Technical-cum-market Feasibility Study for Solar Photovoltaic Equipments and Systems

Final Report

Prepared for

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List of Acronyms

APEDC	Andhra Pradesh Electronics Development Corporation
BARC	Bhabha Atomic Research Centre
BHEL	Bharat Heavy Electricals Limited
BOS	Balance of systems
CASE	Commission for Additional Sources of Energy
CEERI	Central Electronics Engineering Research Institute
CEL	Central Electronics Limited
CSIO	Central Scientific Instruments Organisation
CSIR	Council for Scientific and Industrial Research
CZ	Czochralski
DNES	Department of Non-conventional Energy Sources
DOE	Department of Electronics
DOT	Department of Telecommunication
DST	Department of Science and Technology
ECD	Energy Conversion Devices
EG	Electronic grade
FZ	Float zone
GEF	Global Environmental Facility
GOI	Government of India
IISc	Indian Institute of Science
IIT	Indian Institute of Technology
IREDA	Indian Renewable Energy Development Agency
ISEC	International Solar Energy Congress
MG	Metallurgical grade
MIS	Metal-insulator-semiconductor
MWp	Megawatt peak
NAL	National Aeronautical Laboratory
NASPED	National Solar Photovoltaic Energy Demonstration
NGO	Non-governmental organisation
NOCT	Nominal operating cell temperature
NRSE	New & Renewable Sources of Energy
ONGC	Oil and Natural Gas Commission
PEC	Photoelectro Chemical
PV	Photovoltaic
REC	Rural Electrification Corporation
REIL	Rajasthan Electronics and Instruments Limited
RESPL	Renewable Energy Systems Private Limited
ROW	Rest-of-the-World
SEB	State Electricity Board
SEDA	State Energy Development Agency
SoG	Solar grade
SSPL	Solid State Physics Laboratory
UNDP	United Nations Development Programme
WB	World Bank

1.0 Photovoltaics : Global Scenario

1.1 Introduction

The Photovoltaic (PV) effect which was discovered by Becquerel in 1839 was first put to application in the form of solar cells for providing power to satellites. In 1958, the first solar cell powered satellite was sent in to the orbit. Solar cells satisfied the requirements of long lasting and light-weight power sources for space applications. In addition, they worked more efficiently in undisturbed and uninterrupted intense sunlight available in outer space.

Essentially, solar cells are semiconductor devices, designed to convert solar energy into electrical energy directly. Each cell has minimum two layers of dissimilar semiconductor material which create an electromotive force at their junction. The cell works by pushing free electrons generated by photons of incident radiation due to this force. Different types of semiconductors can be used in a variety of physical states viz; single crystal, polycrystalline or amorphous to fabricate solar cells.

Cells are then connected together electrically and laminated into a module to increase the power output and to provide a protective packaging. Such a module becomes the basic building block of a PV power system. Various modules are suitably interconnected in a series-parallel combination to form panels and array. A complete PV power system has a PV array, an energy storage system and necessary electronic, electrical and mechanical sub-systems, together known as Balance-of-system (BOS). PV system generates DC electricity which needs to be conditioned prior to its use. According to the specified load, DC-to-AC inverter, DC-to-DC converter, various controlling and monitoring instruments are used.

Electrical energy is generated directly by the PV system without involving any moving part. It is feasible to have both centralized as well as decentralized power generation using PV. The gestation period is small. The time taken to design, install and commission the system is significantly less. Since natural sunlight is the only fuel required, the operation of a PV power generator is pollution free.

1.2 Materials and Technologies for Manufacturing PV Devices

1.2.1 Materials

Crystalline (single or poly) silicon is the most common semiconductor material used in PV devices. It has the longest history and the strongest technology base, and it still dominates the global PV market at 12% efficient industrially produced poly-crystalline cells and (14% to 15%) single crystalline cells. It is the best understood of PV materials and its technology continues to advance rapidly (aiming at 30% efficiency under non-concentrated sunlight).

The choice of PV materials is driven by two factors viz; higher conversion efficiency and low-cost materials ultimately leading to cost-effective PV systems which are competitive in the market. Crystalline devices are generally more efficient, but thin-film devices compete with them for their lower cost. Amorphous silicon, polycrystalline thin films and III-V single crystal materials are the main contenders of thin-film technology devices. Of these, the highest efficiencies may be obtained from III-V materials, notably gallium arsenide (GaAs) and its alloys which can even be grown on reusable germanium. Efficiencies can be enhanced further by using these materials in many promising multi-junction designs (37% achieved in the laboratory). However, the fate of these devices is still decided by their relatively high costs.

Hydrogenated amorphous silicon is the leading alternative to crystalline silicon. The layers can be deposited on many inexpensive substrates including glass, steel or plastic. Efficient a-Si solar cells consist of a thin-film of the order of 1 m thick whereas a typical crystalline cell thickness is 100-200 m. This is because the a-Si absorption coefficient is one degree higher than its crystalline counterpart. In addition, the growth temperature for a-Si thin film is much lower (200-400°C) as compared to that for crystalline, making the former less energy-intensive. It is possible to make cells about a sq.m in size which is a key feature in reducing production cost. Amorphous silicon, however, faces the drawback of lower efficiency (~10%) and light induced degradation due to which the devices loose as much as 50% of their efficiency after initial exposure to light. Combined with the inherent low efficiency, the use of a-Si is limited to low power indoor applications only.

Polycrystalline thin films, such as copper indium diselenide ($CuInSe_2$) and Cadmium telluride (CdTe) offer all the advantages of amorphous silicon without facing light induced degradation. They hold the potential for the most inexpensive cell technology, in terms of capital investment and for having very high throughput. Typical efficiencies are in the range of 12 to 14%.

Ribbon technology, which grows entire sheets of silicon, and cast silicon which uses simple casting technique to obtain square ingots which are then sawed into wafers to make cells, are the two approaches to achieve lower production costs in crystalline silicon technology. Polycrystalline silicon thus obtained is less efficient than single crystal silicon grown either by Czochralski (CZ) or Float zone (FZ) methods, but has the potential for using less pure and hence less expensive starting material, achieving low production costs and high throughput.

Single crystal silicon is the most established manufacturing technology today for making PV modules. Outdoor PV applications have been dominated mostly by single crystal and partly polycrystalline silicon PV modules. Both these technologies have established a firm market base. Amorphous silicon technology has been catering primarily to indoor consumer applications. Nevertheless, during 1987-88, these modules were used in outdoor application also.

Despite the fact that amorphous silicon market grew four fold during 1983-87, the technology seems to be loosing ground as seen from the last three year shipments. It has not yet been utilized extensively for large scale power applications. It appears that the future for this technology lies in small consumer oriented applications e.g. home ventilators which were sold in excess of 2,00,000 in the year 1990.

The market for polycrystalline silicon based system, on the other hand, has almost doubled in last three years, thus bringing the crystalline silicon technology to be the main contender for PV industry today.

Inspite of intense R&D and commercialisation efforts on thin-film of all kinds, it is doubtful if the current scenario of dominance of crystalline Si technology will change in near future.

Except for U.S., no other country has shipped modules based on ribbon silicon technology or for concentrator applications during the past few years. Japan had shipped 0.1 MWp modules in this category in 1984, but did not continue after that. Shipments made by U.S. also showed a decline. This sector which represented almost twenty seven per cent of the total U.S. market in 1984 reduced to less than one per cent during 1991. These technologies appear to have failed to influence the market in any significant way.

Tables 1.1 and 1.2 give details about these materials.

Table 1.1 : Present and future status of PV cell technologies

PV Technology	1990	1992	1995
Flat plate crystalline Silicon	22-23% (Lab Cell) 11-13% (Commercial Module)	24.2% (Lab Cell) 14% (Commercial Module)	25% (Lab Cell) 14-15% (Commercial Module)
Flat plat thin films	12-14% (Lab Cell) 4-6% (Commercial Module)	12.5-19.1% (Lab Cell) > 6.3% (Commercial Module)	15-18% (Lab Cell) 8-10% (Commercial Module)
Concentrators	27-32% (Lab Cell) 14-17% (Commercial Module)	27.5-35.8% (Lab Cell) 18-20.8% (Commercial Module)	> 35% (Lab Cell) 20-22% (Commercial Module)

Table 1.2: Theoretical limits and experimental results of conversion efficiency in Solar Cells

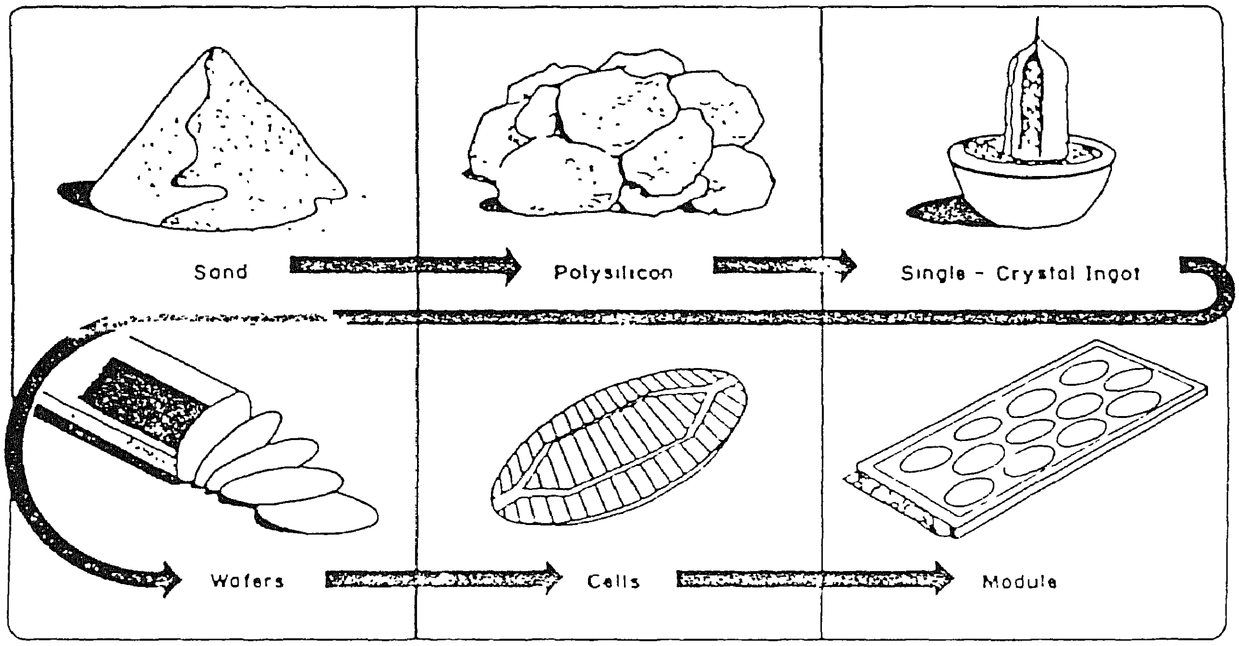
Material	Theoretical Limit (%)		Experimental (%)	
	Flat Plate	Under Concentration	Flat Plate	Under Concentration
Silicon				
Single Crystal	25 ~ 30	34	24.2	27.5
Poly crystalline	20 ~ 22		17.8	
III-IV Semiconductor Single Junction GaAS Heteroface with GaAlAS GaInP	~ 27	34	24.8 25.7	29.2
Single Junction Indium Phosphide	~ 26	33	22.0	
Tandem (4 terminals)				
GaAs/GaSb	~ 34	41		35.8
GaAs/Si	~ 35	~ 42		31.0
Amorphous Silicon				
Single Junction	~ 15		12.5	
Tandem structure	20-24		13.7	
Thin Films				
Cadmium Telluride (CdTe)	~ 20		13.1	
Copper Indium diselenide (CIS)	~ 18		14.1	
Tandem (4 terminals)				
a-Si/CIS	~ 20		15.6	
a-Si/Poly-Si	~ 24		19.1	

1.2.2 Technologies

1.2.2.1 Crystalline Silicon Material Technologies

The standard technology for making solar cells can be broken down into stages shown in exhibit 1.1. Silicon is generally recognised by three different material grades namely those of metallurgical (MG) solar (SOG), semiconductor or an electronic one (EG). One of the offshoots of the last one is the off-specification Semiconductor grade silicon, which is nothing but the scrap of the electronic industry. It contains higher dopant concentrations of boron and phosphorous. The cost and purity levels of silicon increase from metallurgical grade to an electronic one. While MG-Si is available at lowest cost, the semiconductor grade possessed of highest purity level (99.999%) is priced at the maximum. MG-Si is initially derived from quartizite or silica sand.

Exhibit 1.1 Technological route for manufacturing solar cells



The first and foremost task for obtaining a wafer of silicon ready to be processed into a solar PV device involves the processing of raw silicon through various technologically established processes. In the international market, MG-Si is available at $ 0.5/Kg, which soars up to something around $ 70/Kg (Siemens price) on obtaining EG silicon. The most energy intensive step is the one, which involves the energy input of 150 kWh (Kg Si)$^{-1}$ during the deposition of silicon from vapour phase. Reliable estimate made on the economics of PV modules point to an outlay of 40-50% alone on wafer preparation including slicing operation. It indicates that material cost of silicon has a significant bearing on the cost of electricity from PV.

Till now, the distinct advantage of obtaining electronic grade silicon is seen in the way of obtaining higher cell conversion efficiencies, which other grades of silicon can ill offer. However, to propagate a wide spread use of this technology, it has become imperative to identify such material approaches, as may provide solar cell feedstock material at lower prices, though at lower efficiency values as well. Tables 1.3 to 1.5 present briefly all such approaches and their current status.

Table 1.3 : Material grades of silicon

Grade	Source	Impurity (ppm atom)	Purity Level	Promise for PV Application
Metallurgical (MG)	Quartzite (90% Silica)	Al 1000-4350 B 40-60 cr 50-200 cu 15-45 Fe 1550-6500 Mn 50-120 Ni 10-105 p 20-50	96-98%	Metallurgical grade silicon based technology identified by Spherical Bead Silicon Technology is in the offing as a very low cost route to PV technology development
Solar grade (upper graded metallurgical silicon)	MG-Si	10 (comprised of copper and aluminium)	99%	Currently, under active development, its large scale emergence at lower cost levels is expected to boost the PV programme
Electronic or Semi conductor grade	High purity silica	< 1	99.999%	Highly promising for attainment of higher cell efficiencies but time ahead would expectedly see PV industries much reduced dependence on it.
Off-spec Semiconductor Grade (SG) (scrap form)	- do -	Higher dopant conc of Boron and Phosphorous	- do -	Still in a modest use at many places with hopes of its withdrawal seen after successful development of solar grade silicon

Table 1.4 : Present outlook of single crystal silicon growth processes

Technique	*Developer*	*Pulling Rate*	*Ingot weight (conV)*	*Ingot/length/diameter*		*Wafer Thickness*	*Kerf loss* ·	*Main Process*	*Cell Efficiency*
				Conventional	Advanced				
Czochralski (Cz)	Kayex Corpn. (Hamco Divn.)	< 10 cmh^{-1} (Normal)	150 Kgs (2.2 Kgh^{-1})	1 m, 7.5 cm	1.5 m, 15 cm	0.2-0.35 mm	< 50%	Effective segregation of impurities	> 15%
Heat Exchanger	Crystal Systems	1.9 Kgh^{-1} (> 95.5% yield)	-	34 x 34 x 17 cm					
Edge defined Film ted growth (EFG) (Ribbon)	Mobil Solar Corpn	40 cm^2 min^{-1}	-	10 cm width	150 mm dia	0.15 0.30		Efficient utilisation of Si material with no loss involved in slicing/ machining operations	> 12%
Dendritic web growth (sheet growth)	Westinghouse Corpn.	13 cm^2 min-1						No impurity contamination due to absence of crucible/die	> 16.9%

Table 1.5: An overview of polycrystalline silicon growth processes

Technique	Developer	Ingot ribbon dimensions/Wt	Process efficiency	Cell efficiency	Process features	Kerf loss	Pulling rate
Heat exchanger method (HEM)	Crystal Systems	44 cm x 44 cm, 80 Kg	High	15%	Seedless process		
Semix process	Semix			15%	Effective separation of impurities		
Silso process	Wacker	43 cms x 43 cms (100 Kg)	50 W KG^{1}		Low cost silicon availability at minimum material loss	2 mm	1 mm min^{1}
Polix process	Photowatt	60 Kg	Slow	10%	Industrial casting process		
Ribbon Against Drop (RAD)		5 cms width		10% (4 cm x 4 cm)			
Dendritic Web Growth	Westinghouse Corporation	4-8 mm thick, 2-5 cms wide and few mtrs in length	Fine	> 10%	Cost effective method of ribbon production		
Ramp Assisted Foil Casting Technique (RAFT)		10 cm x 10 cms (wafer size)	Fine	5-8-10.3% (5 cm x 5 cm)	Material loss due to slicing avoided completely		
Silicon on ceramic method		10 m thick ribbon	Promising	~ 11%	Large grain size possible		5-6 cms min^{1}
Silicon coating by an inverted meniscus (SCIM)		Several m's thick silicon sheets grown	Fine	-	-	-	-
Hydrogen reduction	Metkem Silicon Ltd	10 cm x 10 cm Wafers	Fine	10%	10 IPA silicon reactor successfully in operation, appreciable energy savings as well.		
Electromagnetic casting	Osaka Titanium Co Ltd.	85 x 85 mm^2 cross section	Fine	13%	Impurity level quite low due to the melting and solidification. Process being out of contact with the crucible		

1.3 The Industry

1.3.1 Origin

Research and development on solar cells continued to be concentrated on space applications till the oil crisis affected the world. In the beginning of the seventies, the rising fuel prices forced the researchers to direct R&D on solar cells towards terrestrial applications. Till then, the lack of a good production-worthy technology and channelised efforts to tap the terrestrial market made the costs and overall stakes too high for any industry to evolve.

During mid seventies, a few industrially advanced countries like the USA initiated national PV development programmes mostly with government funding. Developing countries like India, Brazil and Mexico closely followed the example. These programmes were basically intended to evolve a cost-effective and commercially viable technology aimed at a large scale utilization of PV systems for various terrestrial applications.

These initial investments made by various governments notably those of U.S., Japan and some western European countries, and by some rich individuals and venture capitalists who were motivated by the substantial tax incentives, sowed the seeds of the commercial PV market. Progressive improvement in production technology leading to substantial cost reduction attracted many developing countries to start utilizing this newly developed energy source. The international PV market, thus, gradually started taking shape.

By the end of seventies, multinational oil giants began to take interest in this area of business and eventually became the most significant source of commercial investments, particularly in the U.S. According to an estimate made in 1982 by Centre for Renewable Resources, an independent public interest group in the U.S., almost 80 per cent of the international PV market during 1981 was held by three U.S. industries, all of whom were wholly or partly owned by U.S. oil companies. These companies were Arco Solar (fully owned by Atlantic Richfield), Solar Power Corporation (fully owned by Exxon Oil Company) and Solarex Corporation (at that time partly owned by Amco Oil Company). Various other companies e.g. Shell Oil, Gulf Oil, Mobil Oil etc. had also begun to take interest through substantial investments both in R&D as well as in the area of commercial production.

The early years of eighties witnessed a phenomenal growth in the international PV market. With the entry of new entrepreneurs, manufacturers and associated groups, it underwent noteworthy changes. While the global PV industry continually expanded resulting in some novel technological developments and innovative applicational areas, the growth rate could not follow the optimistic forecasts made earlier both by the government and independent analysists. Primary reason for this shortfall appeared to be the plentiful availability of oil stock and its low market price resulting in substantial reduction in R&D investments, and the lack of attainment of substantial 'breakthrough' in the PV technology, leading to stagnation in the PV market prices which were far above than those forecasted earlier.

Beginning of the decade ninety is once again marked by renewed attention towards solar, specifically PV. Fluctuating oil prices, uncertainties associated with conventional energy sources, and most importantly anti pollution credit seem to be favouring PV. In this regard, the European initiatives are worth mentioning. Germany expressed its consciousness towards developing PV in more than one way. While the annual budget for 1991 worth $ 70 million is the largest in the world, the largest PV industry, Arco Solar, was purchased by Siemens Industries recently and renamed Siemens Solar Industries.

1.3.2 Growth

In an overall perspective, the PV industry has fared well in the non-conventional energy sector over the last fifteen years. The total module shipments which were less than 0.5 MWp in 1975, increased to 55.3 MWp in 1991 representing growth rate of approximately 20% per year. Several hundreds of companies all over the world are associated with PV industry today. There are about forty major manufacturers making PV cells and modules only, others mainly deal with balance-of-system (BOS) components, and integration and supply of PV systems. The PV industry is generally categorized into four country-wise segments, viz; U.S., Japan, Europe and Others. The last category includes rest-of-the-world (ROW) companies mainly of India, Brazil, and Australia. The annual turnover of PV industry is more than $ 300 million.

The overall growth in the global shipments during 1983-91 has been more-or-less steady, except in 1985 when the shipments dropped by about six per cent. This drop was attributed to the fact that one of the-then-major U.S. manufacturers made no shipment in 1985. In fact, the U.S. dominated market underwent a change from 1984 onwards when severe competition with Japan started and the latter took the lead in 1985. Since then, the annual Japanese module shipment has always been higher than that of the U.S. (see Table 1.6 below).

Table: 1.6: World-wide module shipments by country (MWp)

	U.S.A.	Japan	Europe	Others	Total
1983	13.1	5.0	3.3	0.3	21.7
1984	11.7	8.9	3.6	0.8	25
1985	7.8	10.8	3.7	1.4	23.5
1986	7.0	13.4	4.3	2.3	27.0
1987	8.65	12.45	4.7	2.8	28.6
1988	11.3	13.0	6.9	4.0	35.2
1989	14.1	14.2	7.9	4.4	40.6
1990	14.8	16.8	10.2	4.7	46.5
1991	17.1	19.9	13.4	5.0	55.4

The most significant growth for the last ten years has been/during 1988 when the shipments grew from 28.6 MWp in 1987 to 35.2 MWp in 1988. But the actual shipments fell much below the expectations and forecasts in 1989 due to sluggish growth of U.S. PV industry. However, 1991 was marked by an excellent recovery both by U.S. and the global PV industry. Several PV module manufacturers are planning new manufacturing capacities in the 10 MWp per year range leading to a total expansion of upto 90 MWp in the 1992-93 time frame (see table 1.7 below). Exhibits 1.2 to 1.5 present the global PV scenario.

Table 1.7: Module production capacity additions (1992-93)

Company	1991 capacity	New capacity	Cell technology
Siemens (US)	9 MW	6-8	Single crystal
Siemens (US)	0	1-3	Copper Indium Diselenide
Solares (US)	6	1-2	Polycrystal
Solarex (US)	1	2-10	a-Si
Armech Solar (US)	0	5-7	Polycrystal
Ital Solar (Italy)	2	2-3	Polycrystal
BP Solar (UK)	1	2	Polycrystal
Kyocera (Japan)	6	3-5/12	Polycrystal
United Solar (US)	1	2-3	a-Si
ECD/Russia	0	3	Triple a-Si
Photowatt (France)	2	1.5	Polycrystal
Siemens (Germany)	0	10-20	Thin film
Astropower (US)	5	3-5	Polycrystal Si film
Solec Int'l (US)	2	2	Single crystal
Nukem (Germany)	1	1-2	Single crystal
APS (US)	1	8-10	a-Si
NAPS (France)	1	?	a-Si
Chronar (Wales)	1	?	a-Si
Others: TST, Kaneka, Helios, Heliodinamica, Arab Plants, UPG, Italsolar, India, Austria, China, South Africa, Taio Yuden, R&S	20		
	55	+50-90 MW	

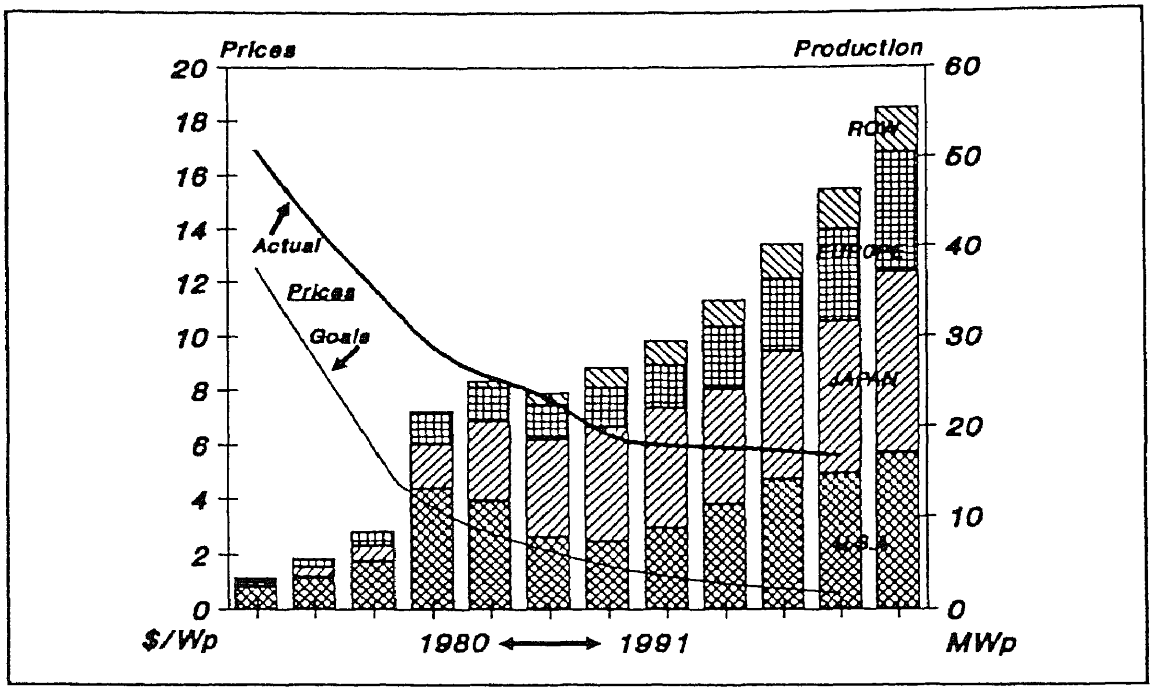


Exhibit 1.2: Global PV production and average prices

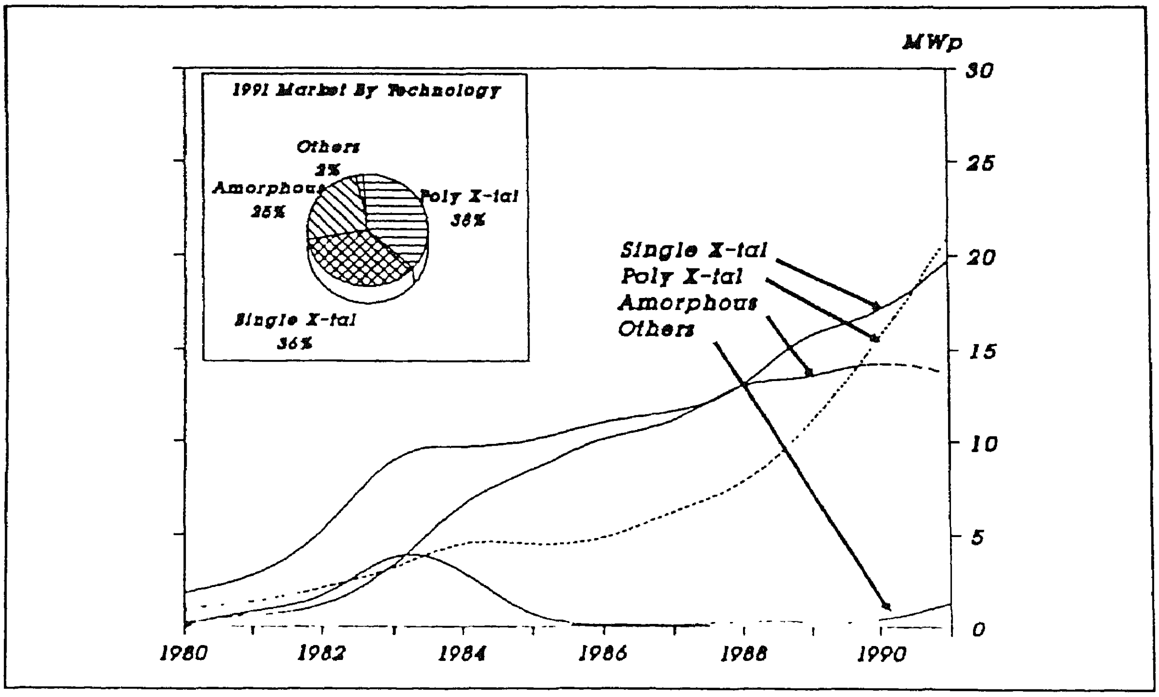


Exhibit 1.3: PV module shipments by technology

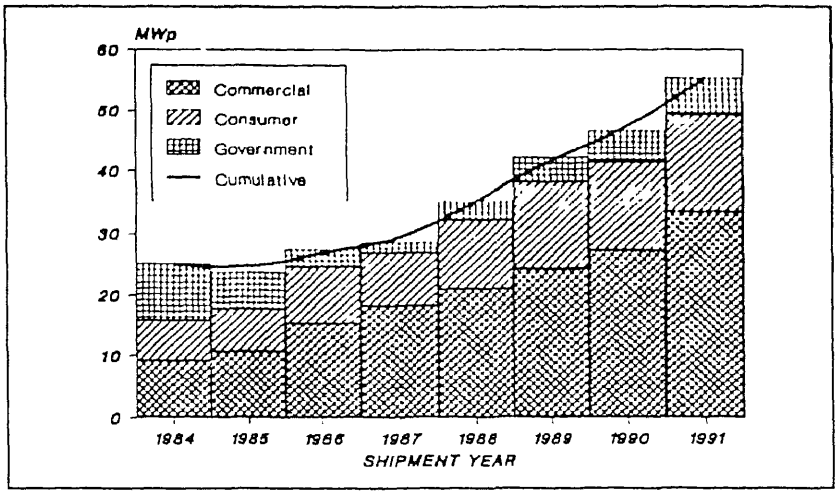


Exhibit 1.4: PV module shipments by application

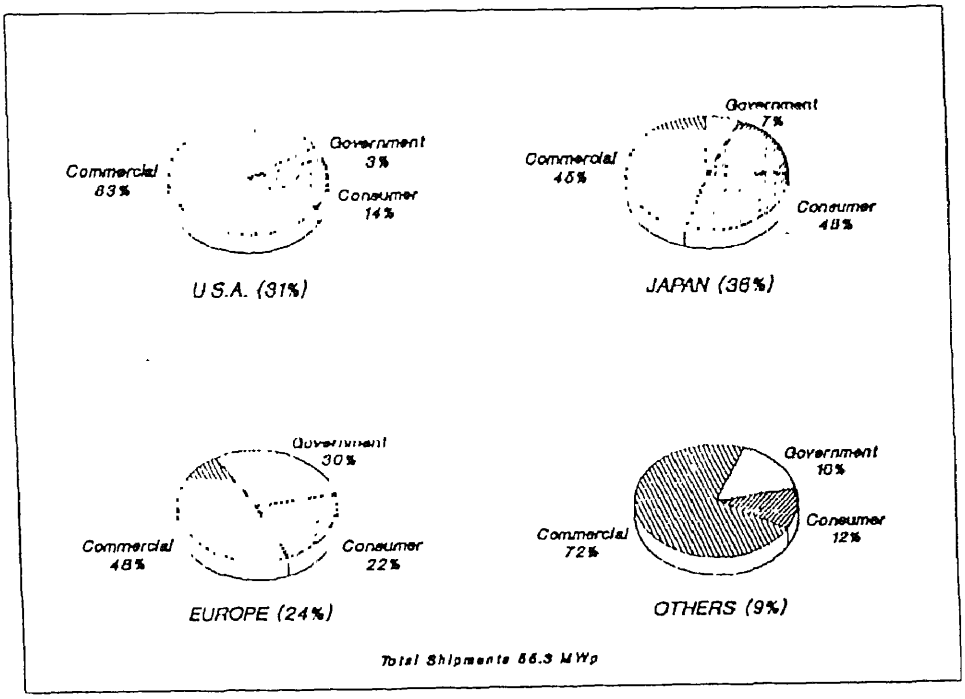


Exhibit 1.5: Structure of 1991 market

1.4 Major Manufacturers and their Growth Curves

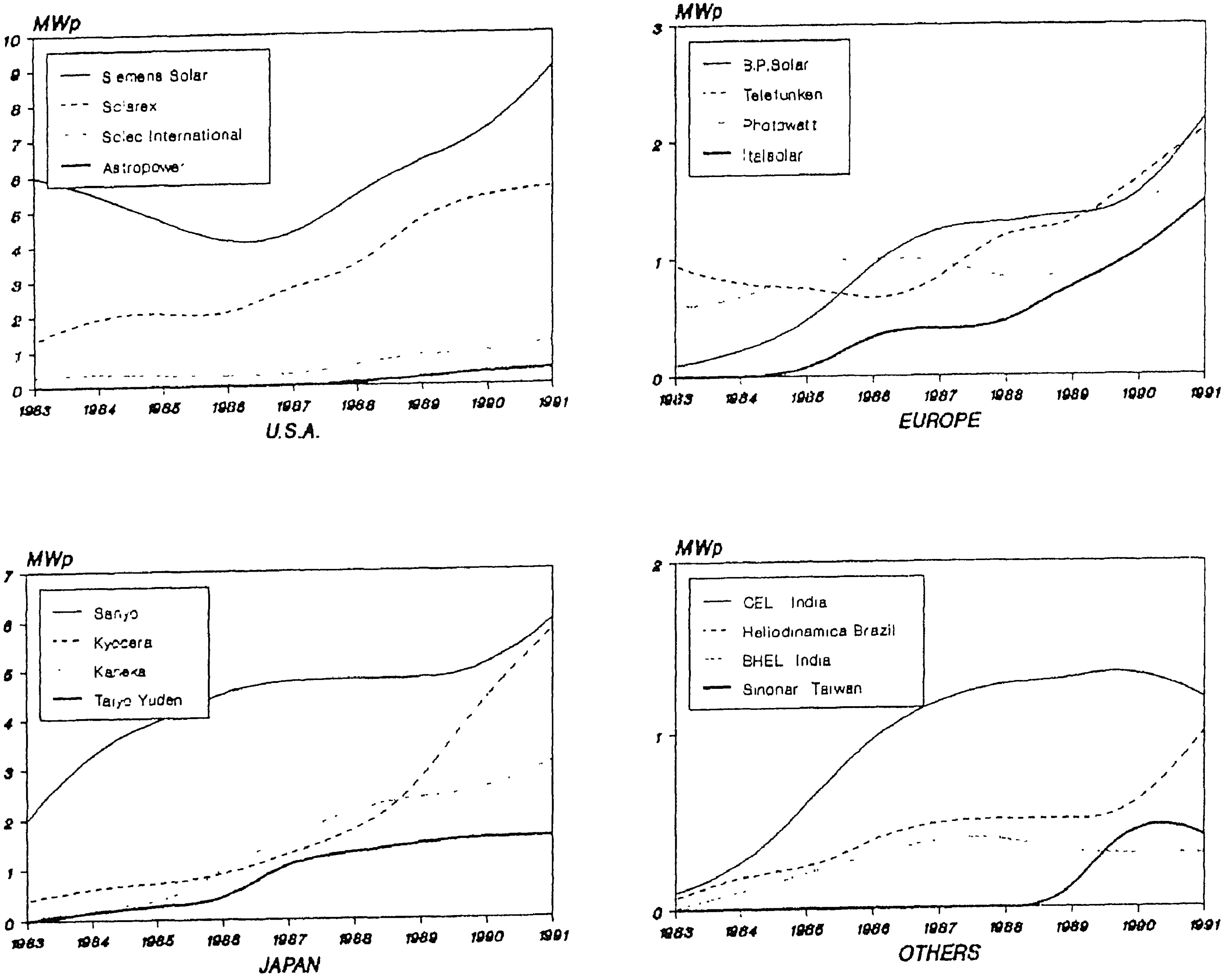
There are about 40 PV module manufacturers all over the world. In addition there are a number of small manufactures who mainly deal with PV systems after buying modules from other sources. All solar cell manufacturers are also module manufacturers but the reverse is not true. There are many module manufacturers who do not produce cells. Table 1.8 below list almost all solar cell and module manufacturers located in different parts of the world.

Table 1.8: Solar Cells and Modules Manufacturers

Companies			
U.S.	Europe	Japan	Rest of World
Siemens Solar	Telefunken	Sanyo	CEL (India)
Solarex	BP Solar Systems	Kaneka	Sinonar (Taiwan)
APS	Naps France	Kyocera	Heliodinamica (Brazil)
Solec International	Chronar Wales	Taiyo Yuden	REIL (India)
USSC	Photowatt (France)	Sharp	Bharat (India)
Entech	Italsolar (Italy)	Hoxan	UDTS/HCR Algiers
Mobil Solar	Helois (Italy)	Fuji	Venergia (Venezuela)
Astropower	Isophoton (Spain)	Matsushita	
	Siemens (Germany)		
	RES (Netherlands)		

Siemens Solar Industries, Germany currently is the leading PV manufacturer. Sixteen per cent contribution of the total module shipments in 1991 came from this manufacturer alone. The top five leaders as per their 1991 module shipment volumes are Siemens Solar Industries, USA, SANYO Electric Co. Ltd., Japan, KYOCERA Corporation, Japan, SOLAREX Corporation, USA and KANEKA, Japan. Except Sanyo and Kaneka, all the other three manufacture both crystalline and a-Si modules. Sanyo and Kaneka are exclusively in a-Si market. Together, these five manufacturers accounted for more than fifty per cent of the global annual module shipments in 1991. Their individual growth curves for last five years indicate the pace at which the industry is expanding (exhibit 1.6).

Exhibit 1.6: Growth curve of major manufacturer



1.5 Equipment Manufacturing Industry

One of the fastest growing segments of the photovoltaic industry is the manufacture and sale of PV module manufacturing and test equipment. Nearly $ 100 million worth of PV manufacturing equipment has been sold in the last few years. As the developing world appreciates the value of PV for providing electricity to its remote villages and farms, their first realization is that they are now importing a very capital intensive product - PV modules. In order to cut the outflow of capital, many opt to license technology and purchase manufacturing equipment from outside the country.

There are now several PV module plants that have purchased all of their equipment and technology from outside the country. These include China, India, Yugoslavia, Canada, Algeria, Wales and France. Several other countries are seriously looking at PV plant purchases.

Key Companies Involved

(Note: PV Equipment Manufacturers are listed in the "PV Yellow Pages" included in this report).

Spire Corporation

Spire Corporation developed a complete line of single crystal silicon module manufacturing and test equipment. The equipment include those for cell diffusion, ion implantation, tabbing machines, laminators, and cell and module test equipment. Spire sold separate pieces of equipment as well as turn key cell and module product lines. Over 20 PV module producers use Spire equipment. Complete Spire lines are sold to Canada, China, Algeria, India and Saudi Arabia. Spire also developed an amorphous silicon module tester that is the standard of the worldwide industry.

Energy Conversion Devices (ECD), Inc.

ECD funded in 1960 has built several generations of a-Si manufacturing plants. In 1982, it designed and constructed a 1.5 MW continuous web roll-to-roll tandem a-Si solar cell processor. ECD is currently doing trial runs in the U.S. of its recently developed three layer web coating plant.

Global Photovoltaic Specialists

Global photovoltaic specialists offer single crystal and polycrystal equipment sold as a complete line or individually, and has sold equipment to India and China.

They are developing polycrystal ingot casting machines and have several major projects under negotiation.

HCT Shaping Systems SA

HCT Shaping Systems in Switzerland has sold ten or more of its multiwire silicon slicing machines. The 500-wire-plus saws can cut hundreds of slices at once with nearly one-half the slice thickness plus kerf of the conventional internal diameter diamond saw. Notable customers include AEG, Solarex, and IBE. A new model introduced in 1988 can cut more slices and can handle a very large ingot of polycrystal material. This new machine has cut crystal and polycrystal silicon material consumption - the largest contributor to cost - by at least 50 percent.

Chronar Corporation

Chronar sells turn key amorphous silicon module manufacturing equipment and technology. The one megawatt annual module production capacity plants are located in Port Jervis, New York; Montgomery, Alabama; Wales; France; Yugoslavia; and China. Chronar's plant represent over $ 60 million that Chronar has been paid for turn key amorphous silicon plants, thus making them the world leader in plant and equipment sales, as well as in module production capacity.

Solec International

Solec manufacturers single crystal modules using reject integrated circuit slices. They offer their proprietary slice preparation and thin film cell process with a laminator as a product.

Crystalox Limited

Crystalox was founded in 1972 to design and manufacture crystal growth systems and high temperature materials processing equipment for both academic research and production within the solid state industry.

Since 1982, Crystalox has been actively involved in the design and production of equipment for processing crystalline silicon for the photovoltaic industry and continues to be a major contributor to the development of the state of the art in this field.

Crystalox has recently collaborated with Italsolar of Nettuno, Italy, to produce a class of furnace equipment and associated process technology designed specifically for the cost effective industrial production of high quality solar silicon ingots.

1.6 Major Applicational Sectors

Broadly, the terrestrial PV applications are divided into (i) stand-alone (residential, industrial and commercial), (ii) consumer (iii) grid-connected (iv) central station (v) exports and government projects.

Stand-alone applications include all those PV systems which are not connected to the power or utility grid. Some representative stand-alone applications are in telecommunication, cathodic protection, railway signal lighting, domestic and outdoor lighting, battery charging, etc..

PV powered watches, calculators, small battery chargers and similar domestic products, mostly for indoor applications constitute the consumer segment of the PV market. This segment is primarily catered by the amorphous silicon cells and modules. These systems are usually designed for less than 10 W of PV power requirement.

Grid-connected applications of PV systems include both residential as well as commercial sectors. In residential applications, the PV array is used to generate a part of the total energy needs of the buildings. Existing grid is used as a back-up source. Commercial grid-connected PV applications include power generation for local-retailers, small industries, manufacturers, etc., with the grid again acting as a back-up. Excess generated power can be sold back to the utility.

Applications where PV systems are used to meet the peaking loads, in areas where the peak demand periods coincide with the sunshine periods, are usually classified in the category of central stations. Normally the central station applications incorporate installed capacities in excess of one MWp.

In the U.S., the government sector also refers to that sector of market which has resulted due to tax-credits claimed by both users and manufacturers. While in India and in almost all developing countries, most of the PV market belongs to government sponsored projects, although the government purchases are accounted for in the commercial sector. The table 1.9 below spans various PV applications.

Table 1.9: Range of PV applications

Tower obstruction beacons	Remote weather stations
Cathodic Protection	Water quality monitors
	Water temperature monitors
	Insolation monitors
Navigation aids	Power for remote residences
Backup generators	Water pumping and control
Automatic gate openers	Lighting
Microwave repeaters	Recreational vehicles
Remote metering	Car ventilators
Emergency call boxes	Race cars
	Commuter cars

The analysis of global PV market is done as per the three end-uses, viz; commercial sector, which includes systems shipped to domestic as also to foreign users, consumer sector, essentially low power applications, and government sector consisting of government sponsored projects.

The commercial sector has traditionally dominated the global PV market, accounting for more than fifty per cent share since 1986. This has lately represented the largest market share in U.S., Europe and also in the ROW countries. The trends over the past few years show that the commercial sector has been steadily increasing due to aggressive efforts at pricing and quality products by most manufacturers to domestic as well as foreign market. Japan has made the maximum shipments in consumer sector mainly due to its dominance in manufacturing amorphous silicon modules which are suitable for consumer applications. The government sector grew for the first time in 1988 and sustained the growth in consecutive year due to a few concentrator projects in some developed countries.

1.7 Trends in Market Prices of PV Modules

1.7.1. Average Module Prices

Average module prices based on annual global shipments are available from various sources all over the world. While the trend followed in all such estimates is similar, variations are seen in actual figures. Also, the prices vary substantially depending on the volume of purchase. The average price quoted in most of the cases is based on some large purchase order. Typically, the actual prices remain about 20-25% higher than the quoted figures. For example, the 1980 module prices by two different sources show a variation of approximately 70 percent. Table 1.10 below gives the same for the years 1980 to 1991 from a single source.

Table 1. . Average module price in 1988 US dollars per Wp

Yc	1980	1981	1982	1983	1984	1985	1986	1987	1988-91
$/Wp	14.0	11.4	10.8	9.2	9.2	7.3	6.5	5.4	5.0-6.0

US industry worth $ 73.8 million in 1990 sold PV modules at an average price of $ 5.68 per Wp in that year. These prices represented an 11% rise compared to the previous year's prices. According to one view, these prices more accurately reflect the true market value of the products because they eliminate the effect of discounting that was frequently practised in the past. As per the data in table 1.11, single crystal silicon technology has been the least cost material over the last six years. Amorphous-Si modules more than six year after introduction of the first a-Si power module, still costs more (or equal) than single crystal and cast silicon modules.

Table 1.11: U.S. average price of PV modules ($/Wp)

	1985	1986	1987	1988	1989	1990
Single crystal Si	5.57	5.2	5.37	4.19	4.98	5.66
Cast and ribbon Si	8.42	7.32	9.13	7.75	4.91	5.68
Thin film a-Si	7.65	6.19	6.69	9.86	5.24	5.65
Concentrator	11.15	15.22	13.71	10.00	10.00	12.28
Other	--	--	--	8.01	--	--
Average	6.69	6.01	6.65	6.10	5.14	5.68

1.7.2 Goals and Forecasts

Although the average PV module prices have come down from $ 55/Wp (1986 US $) in 1975 to $ 5-8/Wp (1988 US $) in 1991, the cost reduction, is far from the ambitious goals cited by the U.S. Department of Energy in late seventies. DOE aimed at developing technology which would bring down the average market price of PV module to $ 2.80 per Wp (1980 prices) by 1983, to $ 0.7 by 1987 and further $ 0.4 by 1990 implying a 52 per cent average rate of decline for every two years, between 1978 and 1990. The actual figures for 1990 are more than ten times higher than these aforesaid goals. European Economic Community (EEC) goals were somewhat more realistic when weighed under current situation. EEC aimed at achieving $ 2 per Wp by 1990 (1980 prices). The actual price in 1991 was $ 5-8 per Wp. Currently, the U.S. DOE R&D programme is focused at achieving near-and-long-term cost goals which are $ 0.12/kWh and $ 0.06/kWh of PV generated electricity.

1.7.3 Manufacturing Cost and Selling Price Forecast

The cost reduction of PV modules depends on a combination of factors:

- improvement in cell efficiency
- cost per watt of silicon used
- use of automation

The analysis incorporating above factors indicates that for a 10 MWp capacity plant, the profitable selling price would be $ 5.5 per Wp if polycrystal silicon was available at $ 25-50 per kg. The gross profit margin over and above the manufacturing cost in this case is 40 percent. Taking the same profit margin for various silicon based technology options, the analysis results in following cost and price forecasts for the years 1995 and 200 for 20 MW plant (table 1.12).

Table 1.12: Manufacturing cost and selling price of silicon based option (1987 $)

Options	1995		2000	
	Cost	Price	Cost	Price
Single crystal	2.6	3.5	1.8	3.0
Poly crystal	1.8	3.0	1.5	2.5
Ribbon (sheet)	2.1	3.5	1.8	3.0
Concentrators	1.2	2.0	1.0	1.66
Amorphous	1.2	2.0	1.0	1.66
Polycrystalline thin-films	1 to 2			

For single crystal processing, following cost reduction options are envisaged:

- continuous melt replenishment
- multiple crystal pulling from one crucible with recycling of scrap
- ion implantation for junction formation
- less expensive silicon
- full automation in the fabrication and assembly steps.

The key to a-Si cost reduction is to get the capital cost per watt produced per year to $ 2 per watt or less and to have 95 percent yields of 6-8 percent efficient, 1-10 sq. ft. cells.

The summary of technology/cost forecast for key silicon-based options is presented in table 1.13 below:

Table 1.13: Summary of technology/cost for key silicon-based options

	1995	2000
SINGLE CRYSTAL SILICON		
- Module Efficiency (%)	17	18
- Profitable Price ($/Wp)	3.50	3.33
CAST INGOT		
- Module Efficiency (%)	16	17
- Profitable Price ($/Wp)	3	2.50
RIBBON/SHEET		
- Module Efficiency (%)	15	17
- Profitable Price ($/Wp)	3.50	3.33
CONCENTRATORS		
- Module Efficiency (%)	20	30
- Profitable Price ($/Wp)	2	1.66
AMORPHOUS SILICON		
- Module Efficiency (%)	10-12	12-14
- Profitable Price ($/Wp)	2	1.66
AVERAGE MODULE PRICE ($/Wp)	2.50	1.50-2.00

1.8 Market Forecast

Several groups all over the world have analyzed the global PV market trends and estimated the market size for the year 2000. One such analysis by PV Energy Systems Inc., U.S.A. is summarised in this section for the benefit of the current study.

The world PV market to the year 2000 has been analyzed under - the "Business As Usual" scenario which assumes that the present environment continues for several years. Specific factors are:

- Oil price remain unchanged
- Interest rates increase and world recession develops
- Risk capital limited ... a 50 MW plant not built
- Technical progress is linear with no major breakthroughs.

The following major sectors are considered.

PV Diesel Hybrid Market

There are 10 million small (less than 200 kW) diesel generators serving base loads throughout the Sunbelt. Two million new generators are sold each year. Studies have shown that PV systems are economical (at $ 10,000/kW installed) for very small generators of less than 5 kW. Typical applications include water pumping, medical refrigeration, water purification and small village power.

As the PV costs decrease, this market will expand exponentially. The saturation level for this sector is 5-10 gigawatts per year. Limited credit availability from the funding agencies makes the purchase of the capital intensive PV problematical. An international finance policy rewarding fully economic systems is required if PV is to serve this large market opportunity.

Worldwide Communications Market

The communication/signal market is the current backbone of the PV industry. PV systems have already been proven to be reliable and economic for providing electricity at remote locations. As a result, PV has been routinely used for powering microwave repeaters, TV transmitters, radio telephones, educational TV, mobile radios, remote signalling, telemetry and other such applications worldwide. This market is growing at a rate of 20-30 percent a year and is relatively inelastic to price. Flat plate thick crystal modules will continue to serve this important sector owing to its proven reliability. This sector is not affected by world energy prices or policy, and thus PV will continue to serve it as the most effective energy source.

Of the annual PV shipments (excluding central station and government projects), communication sales account for 35 to 45 percent of the total annual revenues. The majority of the market is direct international sales.

The communications market can be divided into two sectors: military and civilian. Military sales are for border patrol and communications including microwave repeaters, warning systems, mobil truck-mounted power packs, mobile radios, etc.. Most military tenders are by invitation only to established systems suppliers and are not widely publicized.

The civilian communication systems essentially offer a great promise by bringing rural communities closer, thus slowing the migration to already overpopulated urban centers. Microwave repeaters, radio telephones, TV transmitters and educational TV establish a much needed communication link between the rural masses and urban centers where government agencies dealing with health, irrigation, etc., are located. Establishing these links, therefore, receives the highest priority from the government of the developing countries.

The PV economics and reliability is now well accepted by the international financing institutions. Recently, a telecommunications project in Thailand was initiated with the World Bank funding. A similar project in Colombia was financed with a loan from U.S. Exim Bank. Peru installed over 300 kW in 1986. It appears that financing for telecommunications projects will continue to be easier in the future.

The majority of military communications sales have been in the Middle East, primarily in Saudi Arabia, Egypt and Kuwait in that order. Oman,on the other hand, has powered television transmitters with PV which provide TV transmission to citizens in remote villages.

In Latin America, major PV users have been Colombia, Peru and Chile. Continuing implementation in these countries and formulation of projects in other countries such as Venezuela and Ecuador are expected. The Brazilian communication market has been closed to outsiders as there exists an indigenous PV manufacturing capability (Heliodinamica).

In Asia, large potential exists in India, Pakistan, Thailand and Indonesia. The Department of Telecommunications of India is committed to setting up extensive communication links. PV is being thoroughly evaluated for use in microwave repeater stations as a reliable source of power. Pakistan also has similar plans for providing communication links to villages.

In Africa, a major user of PV has been the Post and Telegraph of South Africa which has aggressively pursued PV over the last 5 years. This trend will continue well into the future. Tanzania awarded its first PV telecommunications project to a British systems house and will pursue more in the future. In addition, PV market for telecommunications in Kenya, Nigeria and Sudan are expected.

Communications market is expected to continue to grow at an annual rate of 25-30 percent until 1995. The declining prices coupled with improving Third World economies and easier financing availability from international financial institutions could lead to a growth rate increase to 40 percent annually to 2000. The projected communication/ signal sales in 2000 are in the 60 MW range.

The civilian communications projects funded by the World Bank or other financial institutions will be a government tender market. There will be extreme competitive pressures on all the bidders, and one should expect procurement delays and long project life cycles associated with a government project. As the demand for PV increases, there will be continual pressure to increase domestic content and foster a domestic PV industry.

Off-the-grid Rural

This sector is often considered as the biggest opportunity of PV-electricity for the billions of persons throughout the world without any electricity at all. However, there are major barriers to large PV markets in this sector:

- The persons with need have little or no money
- PV when "economic" is very capital, first cost intensive
- World Aid agencies are stretched to limit for food, water, health
- Subsidized central electricity and fuel defer economic break even for PV.
- Lack of knowledge of PV. Most buyers want to "see and feel" a working system before a decision to buy is made.
- Unavailability of distribution and service channels. This also is the cause for the lack of knowledge by consumers. Current pricing structures do not allow sufficient profit margins for the established distribution channels.
- Unavailability of proven rugged balance-of-system components that can withstand use by an unsophisticated customer.

This market sector will develop after the year 2000. In order to serve this vast market, in-country manufacturing is required in order to mitigate the balance of payments caused by the capital intensive PV.

PV Consumer Products

This sector has reached a saturation. Most common material is amorphous silicon, with Japan serving 90 percent of the market. Principal products include: calculators, watches, battery chargers, electronic remote controls, AM/FM portable radios, and portable lights. This sector will grow from its present level of 10 megawatts per year to over 50 megawatts annually in the 1995-2000 time frame. If sales of higher power products, including power packs for portable tools, televisions, computers, telephones, motor homes, boats, etc., grow as the prices decrease.

A solid, though limited,commercial market exists today for small off-the-grid stand-alone systems for lighting, entertainment and refrigeration. For example, PV powered refrigerators are gaining popularity in the Dominican Republic for storing cold beer by commercial establishments. Unreliable grid electricity coupled with scarcity and high prices of diesel/gasoline makes PV attractive in this particular application. Even well-to-do farmers almost never have electricity in their farm houses. Small packaged systems can provide electricity for essential uses such as lighting, TV and refrigeration. On poultry farms, longer daylight hours increase productivity of chickens. A fe hours of lighting in the evening can provide higher yield of eggs, thus increasing the farmer's revenues. there are several such uses on the farm and villages that can enhance productivity and quality of life of the village residents.

The result of the analysis under this scenario is shown in the table 1.14.

Table 1.14: "Business as Usual" world market forecast PV modules (MWp) shipped worldwide annually

Market Sector	1995	2000
World consumer products	50	60
World off-the-grid rural	18	20
Worldwide communications, signals	30	40
Worldwide PV/diesel commercial	20	40
Grid connected (MW)	50	100
Total MW	168	260
Price ($/WP) (1980 $)	3	2

1.9 New Products Developed

Table 1.15 lists most of the new products which have been developed in past one year.

1.10 New Initiatives

Major PV initiatives during 1991-92 are presented in table 1.16.

Table 1.15: PV product range (Period of development: 1991-92)

Product	Purpose in brief	Short Description
PV Broadcast Systems	Lending of Public Information during highway emergencies	Transmitters powered by the solar electric power are raised on trailers for onward coupling to an emergency vehicle.
PV Bus stops	Availability of light in bus stops for "in Waiting" passengers.	Lights draw their electricity from 12 Volt battery charged by a 60 WP panel.
Solar PV Car	Commuting Value mainly existing involvement in global PV car races.	Amorphous silicon modules adhered to the different parts of the car provide charge to a battery, which in turns ruins the vehicle.
Solar lantern	Lighting value	A High efficiency luminaire attachment with the module and a mini battery.
Solar Sunroofs	Better passenger comfort in transit	Sunroofs of this kind bear the ability to reduce the internal temperature in a parked car by more than 20°C.
Glass Facades	Useful for buildings meeting their partial or full power needs through PV. Distinct advantages of sound protection and heat insolation also.	Solar electric modules are integrated within the glass envelope.
Air-conditioners	of immense use in ensuring better thermal comfort besides reducing dependence on utility power.	Partaked need met presently roughly ~ 500 W Total power drawn ~ 900 W at cooling capacity of 8350 Btu's
Lightning Protector	For safeguarding the charging regulators against over voltages, which are coupled into the wires between PV array and charge regulator caused by lightning.	50,75, 100 V over voltage protectors designed.
Solar Simulator (Data acquisition system)	For testing of large area film solar cells and modules.	Possess the capability to test module systems with current - voltage ranges of 20 A, D.C and 100 V, D.C.

Electric Fense	Of use in keeping at bay wild animals otherwise intruding into the standing crop fields.	Single panel use able to deliver a large enough shock.
Digital integrating Ampher-hour counter	Intended for ascertaining battery display status in storage batteries up to 1000 AH, PV-wind diesel generators, motor homes, mobile homes, marine systems and Telecom. repeater stations.	Fully automatic counter records up to 999.99 AH with charge and discharge current handling capacity of 70 A, 1240 A.
High Pressure Sodium Lighting Systems	Of use as a preferred, high efficiency and excellent quality system for street lighting.	Lumisol H-P is a complete system including PV modules, batteries, charge controllers, ballast lamp and housing.
PV recharger in computers	Supply of charge for sustaining most laptop computers indefinitely. Acts as a PV charger for batteries of laptop computers.	Three models are available with varying current outputs of 100, 300, 600 mA's weighing 4.3 lbs.
PV Radar detector	For detection of x and K frequency bands, mute and city/highway switches, signal strength meter, signal L&D indicators.	Solar Panel charges a built in NiCd battery for cordless use.
Cellular phone systems	Intended for communication without dependence on power line connections	Such phones powered by PV can be connected to domestic and international cellular network.
Window ventilators	Intended to ventilate houses and apartments locked up for days together	A 6.3 W solar cell powers a fan, that consumes 1-2 watts. Storage is provided by a 1200 mAH Ni-Cd battery.
Car ventilation systems	Of immense use in cooling the interior of a car	An amorphous silicon cell (4.2 W) drives a 3.2 W fan thus providing air at the rate of 1.5 cubic meters per minute.

Table 1.16: Major PV development initiatives during 1991-92

(a) **Initiated**

1 GW of PV by 2000	U.S. Five year PV plan sets the trend for various installations totalling 1 GW through the award of PV manufacturing technology initiative contracts (PVMTC)
Commercial promise of CIS cells by ISET	Massive investment of $ 20 million put in through contractual awards
$ 50 million outlay for cell technologies development	A total of $ 50 million awarded in contracts to seven major PV firms for fruitful development of various cell technologies with special emphasis on thin films
$ 20 million contract to Siemens	Largest single contract in the history of PV awarded to Siemens (Germany) for supply/installation and maintenance of PV systems in Africa
10 MW a-Si (Eureka) plant establishment	Process afoot for the production of about 2 million square feet of a-Si modules in California
100 kW PV grid sound barriers	Swiss alpine highway authorities engaged in designing and development of this novel system
Spherical bead silicon technology development	Texas instruments, Dallas through its novel development of newer cell technology based on low cost metallurgical grade silicon promises commercialisation by early 1993.
Largest grid connected system in Europe	Modalities finalised for the installation of 3.3 MW of polycrystalline silicon modules to be coupled with grid by Italian National Electricity Authority.
Multi-junction a-Si module development	Advanced Photovoltaic Systems Princeton (NJ) awarded a multijunction a-Si module development, contract worth multi-million dollars.
Iranian telecommunication network operation through PV	One of the biggest commercial orders in the history of terrestrial photovoltaics placed by an Iranian telephone company with Germany for establishment of 1 MW of polycrystalline cell line etc.
PV awareness building measures	Japan launches a major initiative for wide spread dissemination of information on promising aspects of PV technology.
PV in building technology	DOE (US) earmarks an outlay $ 5 million for promoting the beneficial use of photovoltaic technology in the building envelope itself.

(b) Envisaged

30 MW thin film plant	Siemens (Germany) conceives the idea of establishment on a-Si/CIS cell technologies.
1000 MW solar dam project	DOE (US) envisages the collection of solar energy by PV collectors on the lines of hydro-dams
1 million PV systems deployment	U.N. supported organisation votes strongly the installations by 1992 with a scope for future growth also
1 MW a-Si plant on stainless steel	United Solar Systems Corporation to build the facility on stainless steel substrates.
Building integrated PV technology	Increased stress to be laid towards the incorporation of PV into the building envelope for meeting in house energy needs
Clearance for energy conservation programme of U.S. Defence (DOD) subject to PV deployment	Contractual award of $ 30 million for energy conservation programme of DOD (US) subject to the pending promise of installation of PV worth $ 6 million

2.0 Status in India

2.1 National Programme

2.1.1 Overview

Before 1975, the activities in the field of solar photovoltaics in India were confined to research and development work in a few national laboratories and the objective was limited to solar cell fabrication only for possible future space applications. However, in 1975, the Department of Science & Technology (DST) initiated a national programme on terrestrial solar photovoltaics under which an integrated approach was evolved for research, development, manufacture, deployment, demonstration and education and training with the active participation of national research laboratories, academic institutions and a public sector electronics company, Central Electronics Limited (CEL). Scientific research on solar cells and development of photovoltaic materials was entrusted to the R&D laboratories and academic institutions whereas product development was assigned to CEL.

During the period 1975 to 1981, various organisations like the Department of Science and Technology, Council of Scientific and Industrial Research (CSIR) and the Department of Electronics (DOE) provided financial support for the terrestrial PV programme. In 1981, the government of India set up a Commission of Additional Sources of Energy (CASE), administratively serviced by the DST. Then, in 1983, a Department of Non-conventional Energy Sources (DNES) was set up and CASE made the policy making body for the area. Presently, the solar photovoltaic programme for terrestrial application is co-ordinated by the DNES which is also the policy and decision making body and main funding organisation supporting solar photovoltaic research and development activity. A number of R&D projects funded by the DNES are being carried out at various laboratories, IITs and universities while both public and private sector companies are engaged in production of PV systems. The total installed capacity is 5.75 MWp per year, while an addition of 2.75 MWp has been announced. Out of the total installed and added capacity, 3 MWp per annum by Suryavonics Limited, Hyderabad has a 100% export commitment. With the involvement of a number of other government agencies in the country, PV systems are being utilised for various applications. PV power sources are already cost effective for powering small, distributed loads not readily reached by existing grid lines.

2.1.2 Initial Efforts and Technology Base

R&D Efforts

Until 1975, activity in the field of solar photovoltaics in India was concentrated only on research on solar cells in a few national laboratories. Developmental activity was directed only towards laboratory-scale solar cell fabrication, mainly oriented towards possible future space applications. The pioneer groups working in this area were those at SSPL, Delhi and BARC, Bombay.

National Aeronautical Laboratory (NAL), Bangalore had been working on EFG ribbons since 1980. Funded initially by the Department of Electronics, the project has developed a set-up for growing 100 mm long, 4.5 mm wide and 1.5 mm thick ribbons from the melt. No solar cell has, however, been made from this material. Metal-insulator-semiconductor (MIS) solar cells have been studied at IIT, Kanpur since 1981. Both single and multicrystalline silicon substrates have been used together with different barrier metals. At present, MIS solar cells on multicrystalline silicon are being studied at IIT, Delhi employing silicon nitride as the interfacial layer. In a photoelectrochemical (PEC) solar cell area, DNES has funded research work at several institutions, notable among these being IIT, Delhi, IISc, Bangalore and IIT, Kharagpur. No significant progress has been made so far in this area.

Scientists at CEERI, Pilani had been engaged in the development of solar cells for use under concentrated light during the period 1979-1984. Efficiency of over 15% was achieved on cells of 15 sq. cm area under one sun operation. Development of plastic Fresnel lenses for concentrating sunlight was undertaken at IISc, Bangalore and CSIO, Chandigarh. Along with these, a system for automatic two-axis tracking of the Sun was also developed at CEERI, Pilani.

Work on polycrystalline thin-film is still at the lab level. A proposal has now been included for building a pilot plant for $CuInSe_2$ solar cells during the 8th plan period.

Technology Base for Terrestrial PV Devices

The development of solar cells for terrestrial applications was initiated at CEL following Government's decision, in 1975, to put concerted efforts in this high technology area. Starting with processing of 30 mm diameter hyperpure silicon wafers using vacuum metallization in 1978, CEL, is now capable of manufacturing, using technology completely developed in-house, 100 mm diameter n+ -p junction solar cells employing low cost techniques like texturisation and screen-printed silver metallisation. BHEL is the other company where a similar indigenous technological and production base has been established.

Silicon Feedstock

Prior to 1986, the entire requirement of silicon wafers for PV production was being imported. In 1986, based on the joint R&D work undertaken by the Indian Institute of Science, Bangalore and M/s. Metkem Silicon Ltd., a subsidiary of M/s. Chemicals and Plastics India Ltd., a 25 tonnes per year poly-silicon plant was established for meeting the requirement of the PV and electronic industries. The process technology employed by M/s. Metkem was based on silicon tetrachloride as the starting material. Even though it was known to have its limitations, the choice was based on its ready availability along with hydrogen in the chlor-alkali plant of the parent company. The technology has proved to be successful in yielding satisfactory quality material. The plant has been in production for the last six years. Downstream facilities comprising of crystal pullers and wafer cutting machines have also been established. During the last two years, poly-silicon technology has been upgraded by M/s. Metkem with financial support from DNES. Important features of the upgraded technology are:

(a) Development of a new design of 10 tonne per year reactor incorporating techniques which result in improvement of yield and reduction of energy consumption.

(b) Effluent recycling system involving a hydro-chlorination loop that enables augmentation of trichlorosilane recycled in the reactor with attendant process improvement.

Presently, polysilicon capacity in the country stands at 35 tonnes per year which can be expanded in a modular fashion in line with demand growth. Efforts are underway to establish adequate conversion capacity into ingots and wafers.

Apart from producing polysilicon feedstock for use in Indian PV industry, Metkem Silicon Limited has also established facilities for growth of single crystalline silicon ingots and slicing these to produce wafers. The company is now supplying silicon wafers suitable for solar cell fabrication to the domestic PV industry.

Crystalline Silicon Solar Cells

Both BHEL and CEL have improved their cell efficiencies to about 12-13% in the production set-up. These improvements have come from improved texturization, better contacts and collector grid designs.

Amorphous Silicon Solar Cells

Amorphous silicon (a-Si) solar cell technology development programme started in 1986, has now reached a stage where the basic single junction cell technology has been developed and utilised in a semi-commercial pilot plant capable of producing upto 1 MW per year of amorphous silicon PV modules. Lab-level efficiencies on 1 x 1 cm^2. have crossed 12% and sub-cell efficiencies in the pilot plant have reached levels above 7%. The pilot plant installed at a location near Delhi, is undergoing commissioning runs, having already successfully fabricated about 2,000 modules of 1 sq. ft. having efficiencies of around 5 percent. The pilot plant design is based on glass-in and module-out concept and is fully automated. The modules made in the pilot plant are being tested for performance including stability characteristics. Research efforts are underway to develop tandem solar cell technology and introduce the same in the pilot plant.

PV Module Technology

In our country, development of PV modules was first taken up by CEL simultaneously with the development of solar cells. During the initial years, solar cells having diameters of 50 and 76 mm were utilised in forming a series string which was then sandwiched between an anodized aluminium plate and a 5 mm thick ordinary top glass plate. An imported encapsulant surrounded the solar cell string. Thin strips of neoprene rubber fixed on the base plate with RTV (room temperature valcanizing) silicone held the encapsulant in place. Finally, suitable aluminium channels fitted on all four sides of the sandwich provided mechanical strength and effective sealing against moisture and other undesirable elements. Over the years, a large number of improvements were made in the moduling technology. Notable among these were incorporation of a tiny expansion loop in the cell interconnect to guard against failures in the field due to thermal shock , replacement of the imported encapsulant by an indigenous one, fixing cells on the top glass plate, use of tempered glass plates both on top and the bottom etc.. For certain special application like offshore oil well head platforms, channels on the sides were made of stainless steel to take care of the corrosive marine environment. With the introduction of 100 mm diameter solar cells in the production line, the size of the module increased considerably. At this point, lamination technology for modules was introduced in CEL using semi-automatic equipment. Basically this process consists of sandwiching a string of solar cells in between thin sheets of white Tedlar, Crane glass, EVA sheets and a tempered low-iron top glass and heat treating the ensemble under vacuum so as to provide effective encapsulation. E-shaped anodized aluminium channels are used on all four sides of the sandwich.

BHEL, which entered into the area of PV later than CEL, and all other module manufacturers are currently producing laminated modules similar to those of CEL.

Table 2.1 gives the technology base and status of R&D in PV.

Table 2.1: Technological base and status of R&D

Technology	Status
Material	
Silicon feedstock	Commercial production
Ingots and wafers	Commercial production
Cells	
Crystalline Si	Commercial production
a-Silicon	Pilot plant commissioned, commercial production in 100% EOU
Polycrystalline thin film	Proposal for building up pilot plant for $CuInSe_2$ during 8th plant period
	CdTe and other materials at lab scale
High efficiency cells	At lab R&D stage
Concentrator technology	Only initial efforts reported
Other semiconductor compounds	Marginal effort at lab level
Module	
Encapsulation	Laminated using semi-automatic equipment
Laminating material	White tedlar, crane glass, EVA sheets all imported
Frame	E-shape anodized aluminium channels
Peak watt	Range 5 Wp - 46 Wp available in full half or quarter size 10 cm dia cells
Interconnections & terminal box	Line expansion loop in the cell interconnect
	Conductive paste of silver and aluminium
	Manually soldered
	Automatic tabbing being incorporated
	Rugged weather-proof nylon terminal box with one extra terminal for monitoring blocking diode.

2.1.3 Financial Outlay and Budgetary Support

The policy at the government level is clearly directed towards a greater thrust on all aspects of PV technology and applications. It has been actively supporting the development of solar photovoltaics in India during the past twelve years. The government spending has been about Rs. 15 crores during 1980-85 period. The major portion of this funding went to set up manufacturing facility for solar cell, module and systems. The budgetary support for PV development in the country increased steadily and reached a level of 12 crores for the financial year 1988-89 (see exhibit 2.1).

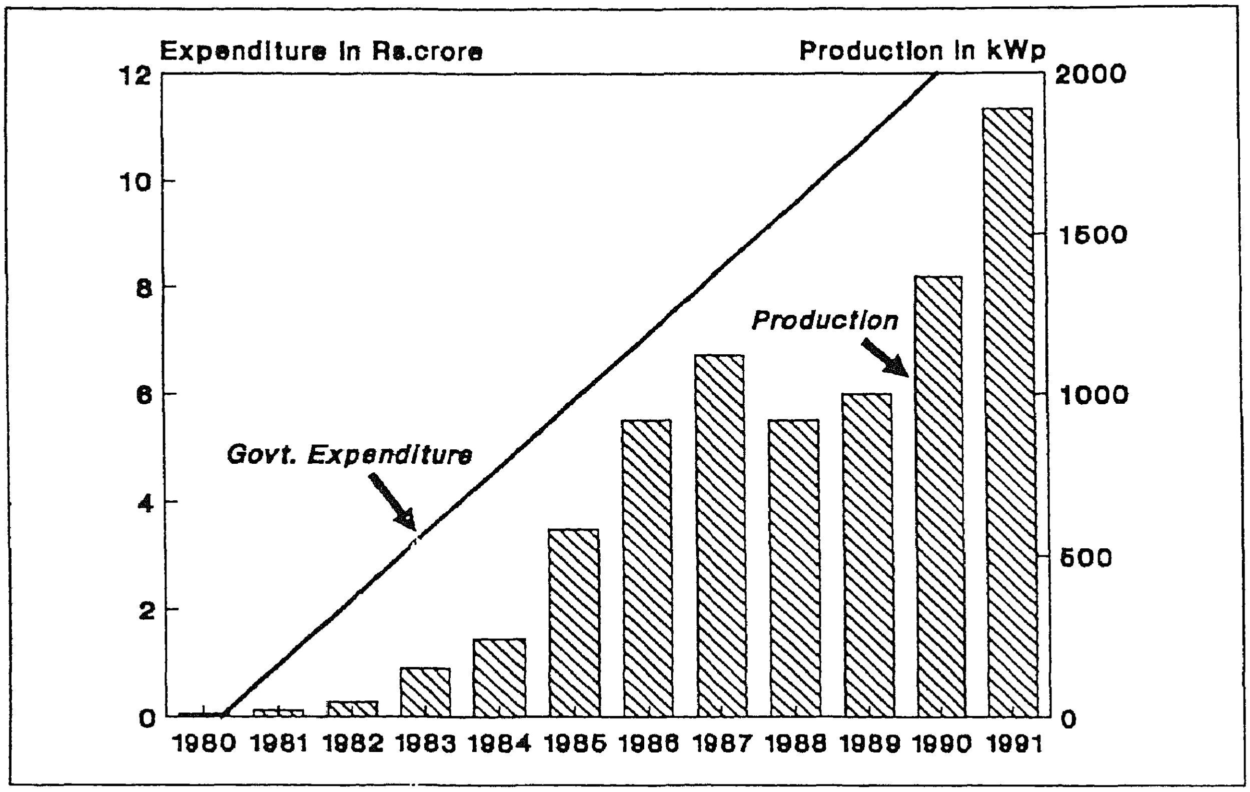


Exhibit 2.1: Indian expenditure and production

During the 8th five year period (1992-97), an amount of Rs. 862 crores has been allocated for NRSE technologies Unlike in the past, the total allocated amount would be split between the Central and State governments. Such an arrangement would enable the states to plan the expenditure on PV without depending on the resources from the central government.

In addition to financial support from the GOI, various international funding agencies have supported the individual PV programme from time-to-time. Currently, the UNDP/World Bank under GEF project has made available U.S. $ 85 million towards commercialisation of PV technology in grid-connected and in stand-alone mode. The project implementation would involve the establishment of a revolving fund for concessional consumer financing, infrastructure support for marketing, delivery and servicing of products and technical support from the DNES to enable quality products to reach a wider customer base. Project funds would be channelled through IREDA.

2.1.4 Project Targets

Eight five year plan

During the 8th plan period, the GOI has set itself following targets.

Scientific goals

18% efficient mono-crystalline cells
15% efficient multi-crystalline cells
13-15% efficient a-Si tandem cells (1 sq. cm)
13-15% efficient poly-crystalline thin-film cells (1 sq. cm)

Technical and cost goals

15% mono-crystalline cells and module at Rs 100/peak watt
13% multi-crystalline cells and modules at Rs. 90/peak watt

Deployment of various PV systems to a total of 30 MWp cumulative capacity requiring a resource allocation of Rs. 400 crores.

GEF Project

Project initiated in the year 1992 involves developing a PV programme for efficient lighting, water pumping and rural community services over five years with a capacity equivalent to 10 MWp. The investment required for this component is estimated at US $ 85 million and would require a minimum GEF contribution of about US $ 17 million (see table 2.2 below).

Table 2.2: Project targets

Project/plan	Duration/ period	Cumulative capacity	Financial resources	
			Required	Assured
Eight five year plan	1992-92	30 MWp	Rs 400 crores	
UNDP/WB supported GEF project	Five year	10 MWp	Rs 221 crores	

2.2 Indian PV Industry

The PV industry in India is relatively new as compared to the international industry. The commercial production of solar cells and modules in India had started in 1983-84 in two public sector organisations, but the actual growth of the PV industry appears to have started only recently. Unlike the international PV industry, in India it did not start with investments from petroleum companies. Instead, the seeds were sown during the five year national programme (1980-85) sponsored at Central Electronics Limited, Sahibabad, a public sector electrotechnology company. The second industry to get interested in PV was the public sector Bharat Heavy Electricals Limited, in the field of power generation. Since then the industry has grown manifold. The actual production is approaching 2 MWp per annum and the turnover of the PV industry is expected to be around Rs. 50 crores. India has the indigenously developed technology and production base from the stage of silicon material to the final PV system integration for crystalline silicon based PV devices. This industry consists of one silicon feedstock and wafer manufacturer, two solar cell manufacturers, six module manufacturers and about fifteen small units mainly engaged in BOS manufacturing and system assembly (see the industry pyramid in exhibit 2.2). In addition, there is a 100 percent export oriented unit with a licensed capacity of 3 MWp based in Hyderabad and 500 kWp capacity commissioned pilot plant for a-Si PV devices.

Catering to scientific needs of PV systems, major battery manufacturers have developed special range of batteries popularly known as solar or PV battery, thus adding another dimension to PV industry. Some of these are Chloride India Ltd., The Standard Batteries Ltd., AMCO Batteries Ltd. and UB-MEC Batteries.

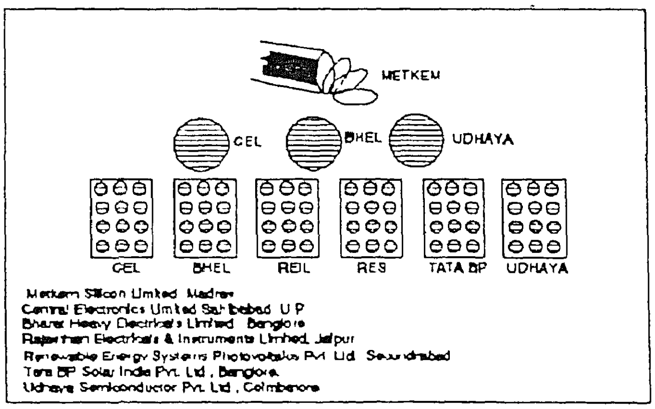

METKEM
CEL
BHEL
UDHAYA
CEL
BHEL
REIL
RES
TATA BP
UDHAYA
Metkem Silicon Limited Madras
Central Electronics Limited Sahibabad U P
Bharat Heavy Electricals Limited Banglore
Rajasthan Electricals & Instruments Limited Jaipur
Renewable Energy Systems Photovoltaics Pvt Ltd Secunderabad
Tata BP Solar India Pvt. Ltd., Banglore
Udhaya Semiconductor Pvt. Ltd., Coimbatore

Exhibit 2.2: Indian PV industry

2.2.1 Corporate Overviews of Manufacturers

- **Metkem Silicon Limited**

Metkem Silicon Limited is the high technology subsidiary of the Chemplast group who are leaders in the chemical engineering industry in India. Metkem silicon is one of the very few semiconductor material manufacturers in the world with the manufacturing facilities from polysilicon to silicon wafers. The 25 tonne p.a. polysilicon manufacturing plant is located at Mettur Dam in Salem District, Tamil Nadu. It is about 200 km from Bangalore.

Metkem silicon uses an indigenous technology for the production of polysilicon that has been developed by the close interaction of the industry with the Indian Institute of Science, Bangalore. The research and development activities at Metkem silicon started as early as 1976. Metkem went into commercial production in 1986.

Metkem silicon's product range consists of polysilicon nuggets of different grades, single crystal silicon ingots of diameters from 2 inches to 150 mm with either boron, phosphorus or antimony doped. Silicon wafers are available as cut, lapped, etched or polished. Polished wafers for the electronics industry are available as 3 inches or 100 mm. Wafers for the photovoltaic market are 100 mm or 125 mm round or 100 mm or 125 mm pseudo square. Metkem silicon also manufacturers wafers as per customer specifications.

For the purposes of technology growth, Metkem silicon has a separate dedicated development group who look into the new product lines and technologies with the global industrial scenario in mind. The team also has a customer support group who from preorder stage to product stabilisation are available at the customer's premises.

- **Central Electronics Limited**

Central Electronics Limited, a public sector enterprise of DST, was financed in 1977 to demonstrate the feasibility of making solar cells and modules on a small scale. By the beginning of 1980, this was successfully demonstrated and a few stand-alone PV energy systems were installed in selected institutions. The success of this project led to the formulation of a five-year (October 1980 to September 1985) national programme, called **NASPED (National Solar Photovoltaic Energy Demonstration)**, with a total allocation of approximately Rs. 12 crores. CEL was the implementing agency on behalf of the Department of Non-conventional Energy Sources of the Government of India, which had meanwhile taken up the management of renewable forms of energy from DST. Major goals of the programme were:

1. Development of manufacturing technology on a pilot-scale for solar cells, PV modules, various BOS components and subsystems and integrated PV systems;
2. Installation and demonstration of a large number of various types of PV systems;
3. R&D on cost reduction and improvement in reliability of various useful PV systems;
4. Building up a competent work force in this area; and
5. Creating public awareness and educating users on various types of PV energy systems.

The NASPED programme in CEL was successfully completed in September 1985. CEL's pilot scale production of solar cells and modules reached a level of about 200 kWp per annum by the end of the programme. A number of stand-alone PV energy systems were installed in various parts of the country. These include water pumping systems both for drinking water and irrigation supplies, domestic and outdoor lighting systems, radio and television receivers, agricultural implements, telecommunication links, battery charging units, etc..

During the tenure of the NASPED programme, CEL started expanding its commercial manufacturing capacity. Currently it has the largest installed capacities for both cells and modules. With partly-automated equipment mostly procured from abroad, the installed cell production capacity is approximately 1.7 MWp per annum. The production is currently based entirely on single-crystalline silicon wafers. However, multicrystalline silicon cells can also be produced in the facilities set up. The module assembly and laminating capacity is over 1 MWp per annum. In addition, CEL has set up manufacturing facilities for various types of electronics for luminaries, control and monitoring equipment for PV power units, etc. It has also set up manufacturing facilities for various types of conducting pastes used in the manufacture of solar cells. It has in-house facilities for wafering silicon ingots.

CEL has been playing an important role in the National Technology Missions oriented at rural upliftment through provision of clean drinking water, adult education, and rural telecommunication and immunization. The following list shows the number of PV systems supplied by CEL from 1985-86 to December 1991.

Sr. No.	System	Quantity
1.	Lighting systems	12495
2.	Water pumping systems	1029
3.	Community TV sets including Direct Reception TV sets via INSAT	1697
4.	Communication systems	7318
5.	Defence systems	111
6.	SPV sources for very low power TV transmitters	101
7.	Medical refrigerator systems	20
8.	Obstruction warning systems at airport	23
9.	Unmanned railway level crossing systems	20
10.	Village power packs	19
11.	Cathodic protection systems for oil/gas pipelines	12
12.	Offshore oil/gas platforms	27
13.	Others	74
	Total	22946

- **Bharat Heavy Electricals Limited**

Bharat Heavy Electricals Limited, a Government of India undertaking, commenced manufacture of Solar Photovoltaic Cells and modules at its Bangalore Division from 1983 with most of the equipment being imported. The current installed capacity is 0.25 MWp for both cell and modules. BHEL's entry into the photovoltaic scene has been in line with its commitment to the development and manufacture of various forms of power generation equipment. As the largest manufacturer of power generation equipment in India, BHEL has also been in the forefront in promoting the use of alternate sources of energy like solar, wind, magneto hydro dynamics etc..

The Electronics Division of BHEL where the photovoltaic modules are manufactured has been involved in the design and manufacture of sophisticated electronic control systems for various applications and power semiconductors since 1977. This expertise in the manufacture of power diodes and thyristos with the system engineering support has enabled BHEL to make rapid strides in the design, development and manufacture of photovoltaic modules and systems. Various systems ranging from power supplies for gas detection and telemetry systems on unmanned offshore platforms to stand alone street lighting systems for remote villages have been deployed by BHEL all over the country.

BHEL photovoltaics - list of supplies for various applications

Sr. No.	System description	Qty. supplied
1.	PV street lighting system (manual on/auto off)	664 nos
2.	PV street lighting system (auto on/auto off)	2500 nos
3.	Water pumping systems (fixed structure)	28 sets
4.	Water pumping systems (manual tracking)	211 sets
5.	Gas and telemetry power source for offshore platforms	24 sets
6	Railway signalling and interlocking systems	4 sets
7.	Railway distant signalling systems	176 sets
8.	Railway microwave station power supply	2 sets
9.	TV and radio systems for community centre	29 sets
10.	School lighting system	1 set
11.	PV power supply for milk tester	10 sets
12.	PV modules for shock fencing	60 nos
13.	PV modules for battery charging (communication sets)	2500 nos
14.	PV systems for P&T telephone exchange	2 sets
15.	PV power supply for data collection platform	51 sets
16	PV systems for track circuits	8 sets
17.	5 kWp power plant	2 sets
18	PV modules for R A X	12 nos
19	PV deep well pumping systems	12 sets
20	PV modules for fisheries cold storage unit	1 set
21	PV system for P&T microwave repeater stn	2 sets
22	PV system for IOC retail outlet	1 set
23	PV system for navigational buoys	4 sets
24	PV system for microwave repeater station	1 set
25	PV system for rural radio phones	550 sets
26	PV system for VIPs	3 sets
27	PV modules for power plants	95 kW
28	30 kW power plant	1 set
29	10 kW power plant	2 set
30	PV system for aviation obstruction light	1 set
31.	PV modules and cells for various applications	725 kW

- **Rajasthan Electronics and Instruments Limited**

In 1984, CEL transferred its module assembly, lamination and systems technology to another public sector enterprise, Rajasthan Electronics and Instruments Limited (REIL), located about 280 km from CEL at Jaipur. REIL has put up a module manufacturing capacity of 1 MWp per annum with imported laminator and test facilities. It procures silicon solar cells from CEL, assembles them into modules, and manufactures various types of systems. It has developed a number of small-scale supportive industries who act as subcontractors to manufacture many components and subsystems needed for modules and systems.

- **Udhaya Semiconductor Private Limited**

Amongst those who are putting up production facilities, without a foreign technology transfer, is Udhaya Semiconductors Pvt. Ltd. (UDAYA), a company earlier manufacturing electric motor pump sets in the private sector in Coimbatore, Tamil Nadu. Udaya has a licensed production capacity of about 300 kWp per annum. By early 1988, this company demonstrated the production of high-quality 100 mm diameter single-crystalline silicon cells and silicone-cast modules. It has imported some production equipment and fabricated some more in-house including a module laminator. Udhaya, with its recent entry in the Indian PV market, offer module in the range of 4-46 Wp capacity.

Applications

Security lighting
Community lighting
Advertisement
Solar PV crop sprayer
Udhaya solar PV submersible pumps
Motor
Pumps

- **Renewable Energy Systems Private Limited**

Another small-sector private company in Hyderabad, RES Photovoltaic Pvt. Ltd., (RESPL) has installed a 0.5 MWp per annum module assembly plant. The plant has been set up with equity participation from the Andhra Pradesh Electronics Development Corporation (APEDC or APEL, a State-government promotional agency), using locally designed and fabricated production equipment. This venture procures cells from either CEL or BHEL or Udaya for this purpose. The company, under another name, is already producing and marketing various types of luminaries and electronics for photovoltaic applications.

- **Tata BP Solar India Private Limited**

Tata BP Solar India Pvt. Ltd. is a joint venture between Tata Exports and Tata Electric, controlling about 60% of the equity and BP solar international, a venture company of British petroleum with a 40 percent stake. BP Solar is one of the world's three major solar companies with over a decade experience in research and manufacture of solar energy equipment.

Tata BP makes solar batteries indigenously. The TATA BP photovoltaic series comes in the 5, 10 and 30 ampere units with a battery charge regulator that is geared to deal with both under-voltage and overcharging.

The electronic invertor developed by the company is currently sourced overseas as part of the arrangement with BP Solar International. The arrangement will also see that the Indian unit will supply solar energy units in the international market. Tata BP, which has an export commitment of 20 percent of total sales by 1995, currently exports electronic systems for the solar package worth $ 42,000.

Operating on a total systems solution, the company offers turnkey solution that include supply, commissioning and future maintenance. The P series batteries of BP Solar International are used as the prototype by Tata BP.

In the plug-in lighting series, Tata BP offers five packages, typically including a 35 watt solar module, a 12 volt, 90 AH PV battery and an electronic control unit. This integrated module can be used to power fluorescent tubes, DC fans, DC B&W television sets or electronic alarms with specific modifications.

The company product range also includes a variety of portable solar systems. The solar water purifier system is expected to be marketed in the aquaguard slot with the added incentive of a lighting appliance. With a maximum flow rate of 1 litre and a water head of 10 feet, the system operates on 12-volt DC photovoltaic battery.

Another major project area contract being pursued by the company now is a medical refrigeration system. A part of the cold-chain expanded programme on immunisation sponsored by the World health Organisation (WHO) and UNICEF, the company is set to supply solar refrigerator system with ice-pack freezers geared to store vaccines.

- **Suryovonics Limited**

Recognising the potential of a-Si material at the infancy stage of the technology, a Hyderabad based entrepreneur promoted a company called Suryovonics Ltd. in collaboration with Energy Conversion Devices U.S.A. with an idea of setting up an export oriented project in the a-Si field. The goal was to establish a mother plant for making jumbo rolls of stainless steel foil on which a-Si has been deposited (by breaking down silene gas) and another plant for making PV systems using this a-Si coated steel. The coated web, besides being used for captive consumption in the module plant, would also be sold to other module making companies.

ECD has developed the PV technology enabling upscale ability and economies of scale in the production of amorphous silicon alloy PV modules. The production utilises the continuous roll-to-roll process requiring very little labour and utilises thin, light weight, easy to handle, flexible, rugged stainless steel substrates. The manufacturing process produces a multi-layer, multi bandgap, multi-cell device in a single pass.

Production in this facility commenced in April 1990 and in 1990-91 around $ 230,000 worth of PV systems were exported, mainly to the U.S. for consumer, military and marine applications.

Suryovonics now makes around 25 different types of PV systems for civilian consumer, marine defence, battery charging and power array applications. Panels of maximum 33 watts are now being made but very soon a 37.5 watt foldable panel for the U.S. army will be manufactured while design work is on for 48, 52 and 55 watt panels demanded by Singapore based buyers.

The selling price at present is $ 7 to $ 10 per peak watt for the larger panels (over 20 watts) and $ 10 to $ 12 per peak watt for smaller ones. This is likely to come down by 25 percent when the web coating machine is commissioned and further down to $ 3 to $ 4 per peak watt in another five years, that is, by 1994-95.

2.2.2 Storage Battery Manufacturers

There are four major private sector lead-acid storage battery manufacturers offering PV batteries in India: Chloride India Limited in Calcutta, AMOCO Batteries

Limited in Bangalore, Standard Batteries Limited in Madras and UB-MEC Batteries in Bangalore. In addition, there are many small manufacturers offering similar storage batteries to the photovoltaic industry. These manufacturers normally offer off-the-shelf lead-acid storage batteries for the photovoltaic industry.

Recently, Chloride has came out with a low-maintenance tubular plate lead-acid battery for photovoltaic application. This battery was originally developed for Railway and telecommunication applications. However, this has found favour with the photovoltaic industry. Remaining three and Crompton-Greaves have also come out with similar battery. In addition, Tata BP Solar uses indigenously developed PV battery for its in-house designed systems

Recently, Amar Raja Batteries Private Limited in Triputi in technical collaboration with GNB Industrial Battery Co., U.S.A. and Plumac Power Systems Private Limited, Hyderabad, have introduced sealed maintenance free absorbed-electrolyte lead-acid storage battery meant for PV systems among several other application. All these available PV batteries come in ranges of 2 V, 6 V and 12 V with varying Ah capacity.

M/s. SAB NIFE A.D., Sweden, world leader's in Nickel-cadmium batteries in a joint venture organisation in Hyderabad offer NIFE-SUNICA range for PV batteries. SAB NIFE Power Systems Limited also offers a range of electronic products suitable for PV applications.

2.2.3 BOS and System Manufacturers

In the BOS and integrated systems, a number of small and medium scale private sector firms have stepped in. Mostly, these companies have been manufacturing electronic and electrical sub-system components and total PV systems with modules procured from one of the six module manufacturers. Ritika Systems Private Limited, a Delhi based unit having an annual turnover of Rs. 2.5 crores is the largest system supplier other than the module manufacturers themselves The unit has sold upto 20,000 PV systems so far. A few notable ones are Indfoss Industries Limited in Delhi, Solar Power Equipment in Madras, Geetanjali Electronics in Calcutta and Amar Enterprise in Bulandshahar, U P Table 2.3 gives a list of BOS and battery manufactures to PV industry.

Table 2.3: BOS and battery manufacturers to PV industry

Solar Power Equipments
Madras

Ritika Systems
New Delhi

Geetanjali Solar Enterprise
West Bengal

Indfos Industries Limited
New Delhi

Shivshakti Electronics Pvt. Ltd.
New Delhi

Amar Enterprises
U.P.

U.P. Hill Electronics Corpn. Ltd.
Lucknow

Sophos Engineering Pvt. Ltd.
New Delhi

Kerala Electronics New Corpn. Ltd.
Trivendram

Surya Jyoti Devices India Pvt. Ltd.
New Delhi

Solar Lighting Works
Dehradun

Teletronix India Ltd.
U.P.

Amar Raja Batteries Ltd.
Tirupati

SAB NIFE Power Systems Ltd.
Hyderabad

The Standard Batteries Ltd.
Bombay

Crompton Greaves Ltd.
New Delhi

Pluman Power Systems (P) Ltd.
Hyderabad

Chloride Solar
Calcutta

UB-MEC Batteries Ltd.
Bangalore

AMCO Batteries Ltd.
Bangalore

2.2.4 Production Capacities and Volume of Production

2.2.4.1 Specification of PV Devices Manufactured in India

Silicon Wafer

Silicon Wafer Specifications

Growth type	CZ
Diameter	50 to 150 mm
Thickness	220 microns above
Dopant	Boron, Phosphorous or Antimony
Orientation	<100> or <111>
Resistivity	Milliohms to 25 ohms
Surfaces	As cut etched, lapped or polished
Carbon	$< 1 \times 10^{16}/cm^3$
Oxygen	$< 1 \times 10^{18}/cm^3$
Dislocation densities of as cut wafers	$< 400/cm^2$
Polished	$< 100/cm^2$
Minority carrier life time	> 20 microseconds
Other geometries (for PV only)	100 mm and 125 mm Pseudo square

Solar Cells

Standard cells made in India are round in shape with 100 mm diameter based on single crystalline silicon material. A thin p-type wafer is taken through phosphorous diffusion process. Front and back electrical contacts are screen printed to this p/n device. The contact material is selected for maximum electrical performance and stability. Each cell generates approximately 0.5 V and 2 ampere under Standard Test Condition (viz; 1000 Wm^{-2} solar insolation of AM 1.5 quality and 25°C cell operating temperature). Half or quarter size cells are also used for low power modules.

Solar Module

The module is typically rated for an operating current of 1.97 amperes at 16.2 V DC. Each module consists of 33/36 solar cells. The cells are stringed in series with dual stern relief loop using suitable interconnects for redundancy. The string is then laminated in ultra-violet resistant polymer (EVA) using TEDLAR and crane glass and mounted behind a high transmission toughened glass surface. Anodized aluminium frame provides structural support for working and stock resistance.

The open circuit voltage of a 36-cell module is 21.0 V, while the short circuit current is 2.2 ampere. Approximate weight is 5.2 kg with typical dimensions equal to (1012 x 403 x 41) mm.

2.2.4.2 Capacities Installed and Enhancements

The total installed capacity base for cells and module in India is 5.75 MWp represented by three central public undertaking, one state public unit and four private sector units. Out of these eight units, one pilot plant has not yet reached the commercialisation stage, two have started shipping products recently and one is a 100% export oriented unit. In fact, there are a few entrepreneurs, organisations who after showing initial interest in this area and getting industrial licenses and letter of intents issued, have not gone ahead with the project at all (see table 2.4 below). Among the similar lines are a few recent announcements and press releases about initiating a new venture. Considering such cases, and the fact that no licensing is required to start a PV industry, a realistic measure of the capacity base is only the total installed capacity and/or organisations registered with the DNES. Unless the industry is set-up and production starts, these interests and announcements do not carry much weight.

Of the seven cell and modules manufacturers, BHEL, Tata BP and Suryavonics have announced their respective future expansion plans. CEL had announced the government approval for increasing its installed production capacity to 5 MW p.a.. However, the currently available installed capacity in CEL is not being fully utilised. Therefore, the capacity enhancement has neither been attempted so far by CEL not is planned for near future, as learnt from reliable sources.

BHEL has recently planned to double its production capacity from .25 MWp to .5 MWp p.a.. The large and most talked about DOT order for rural telephones has been the incentive for this short term expansion plan. On a long term basis, no enhancement plan has been announced by BHEL.

Table 2.4 List of Organizations/Groups having Received Letter of Intent to set up Manufacturing Facility for PV Cells and/or Modules

PARTY_NAME	PLACE	ITEM	CAPACITY	UNIT	IL_LI_NO	ISSUEDATE	FOREIGNCOL
Gautam Shah	Ahmedabad	PV Modules	1000	kW			
Central Electronics Limited	Sahibabad	PV Cells,Modules,Systems	5000	kW	DGTD Regd.	30-08-80	
Continental Devices India Ltd	New Delhi	Solar Cells	1000000	No.	CIL-66/83	25-02-83	
Thyristors Controls Pvt Ltd.	Ahmedabad	PV Modules & Systems	1000	kW	LI-419/84	18-06-84	
Jyoti Ltd.	Baroda	SPV Systems	1000	No.	LI-538/84	19-07-84	
State Indl Invest Corp of Maharastr	Bombay	PV Systems	1400	No.	LI-748/84	01-10-84	
Ravi C. Krishnan	New Delhi	a-Si Modules & Systems				01-01-85	GlassTech, USA
A.P. Electronic Development Corpn.	Hyderabad	PV Modules/Systems	10000	No.	LI-506/85	12-04-85	
Shiv Shir Shelar Enterprises	Delhi	PV Arrays/Solar Cells	5000	kW	LI-749/85	14-06-85	
Kerala State Electronics Dev Corp	Trivandrum	SPV	120000000	No.	R-181/85	25-06-85	
Keltron Power Devices Ltd.	Trichur	PV Cells & Modules	1000000	No.	R-739/85	17-10-85	
Orien Engineers Pvt. Ltd.	Orissa	PV Panels/Appliances	27000	No.	R-737/85	17-10-85	
Ajay Paul	Saharanpur	PV Modules	80000	No.	R-796/85	29-10-85	
Indo-American Development Corpn.	U.S.A.	PV Cells,Module & Systems	3000	kW	LI-1169/85	04-11-85	
Danfoss (India) Limited	Faridabad	PV Modules	600	kW	LI-1175/85	08-11-85	
Methodex Systems Pvt. Ltd.	New Delhi	PV Modules & Systems	1000	kW	LI-1177/85	08-11-85	
Technology Park Ltd.	New Delhi	PV Modules	5000	kW	LI-1176/85	08-11-85	
Solid State Devices India Ltd.	Hyderabad	PV Cells	2000	kW	LI-1214/85	26-11-85	
A. Srikendarajah	Madras	PolyXtal Cells/Modules	2500	kW	LI-1269/85	12-12-85	
Neelam Rajender Rao	Hyderabad	PV Modules & Systems	500	kW	LI-1270/85	12-12-85	
Vinod C. Vashishth	U.S.A.	PV Modules & Systems	1200	kW	LI-1265/85	12-12-85	
ECD Dev Corp of Goa Daman & Diu	Panaji	PV Modules	250	kW	R-316/86	25-03-86	
Khandelwal Herman Pvt. Ltd.	Bombay	Power Module Assembly	500000	No.	R-749/86	09-07-86	
Surya Solar Ltd.	New Delhi	Solar Cells	1000000	kW	R-781/86	18-07-86	
Andhra Cement Co.	New Delhi	PV Modules	10000	kW	DGTD Regd.	01-08-86	
Western India Enterprises Ltd.	Poona	PV Cells & Modules	5000000	No.	R-913/86	11-08-86	
Solar India	New Delhi	PV Cells & Modules	100000000	kW	R-703/87	29-04-87	
Maharashtra Electronics Dev Corp	Bombay	PV Pumps & Subsystems	30000	No.	LT-534/87	18-09-87	
M. Varadarajan, Suryovonics	Hyderabad	PV Cells & Modules	3000	kW		19-04-88	
Zodiac GlassTech Solar Pvt. Ltd.	Bombay	Solar Cells & Panels	3000	kW		01-05-88	
Surya Jyoti Deveices India Pvt Ltd.	New Delhi	a-Si Cells etc.				01-09-88	Chronar, USA
Suryavonics	Hyderabad	a-Si Cells & Modules				01-09-88	ECD, USA
Tata Exports Ltd.	Bombay	PV Modules & Systems				01-09-88	BP Solar, UK
West Bengal Electronics Dev Corp	Calcutta	Cells, Modules & Systems	1000	kW		16-09-88	

The same has been true for REIL which is planning to set up a 1 MWp p.a. cell line facility. The DOT order, on one hand has created a scarcity of CEL cells to REIL as CEL itself has received the largest part of the order. On the other, it has provided incentive to REIL to expand its production base. The planned expansion however, would not effect the total module production capacity of REIL. Instead of buying cells from CEL, REIL would then be utilizing in-house manufactured cells, thereby achieving a better capacity utilization of its module line. Suryavonics, with 3 MWp licensed capacity, has only installed 1 MWp till now. A further addition of 2 MWp has already been initiated. Similarly, Tata BP Solar's installed capacities of 0.5 MWp p.a. is currently being upgraded to 1 MWp. Table 2.5 gives the status of PV industry.

2.2.4.3 Volume of Production

The first batch of silicon solar cells were produced by a company in India in 1977. These were 50 mm diameter single crystalline cells, having vacuum evaporated titanium-palladium-silver contacts. Silicone-cast modules made out of these cells, and operational water pumping and telecommunication systems, were displayed in the International Solar Energy Congress (ISEC) Exhibition in Delhi in January 1978. The pilot-production of PV products started in CEL under the Government sponsored NASPED programme. Not all the solar cells produced by CEL are used in-house to produce modules. The production of modules by REIL was dependent on cells procured from CEL.

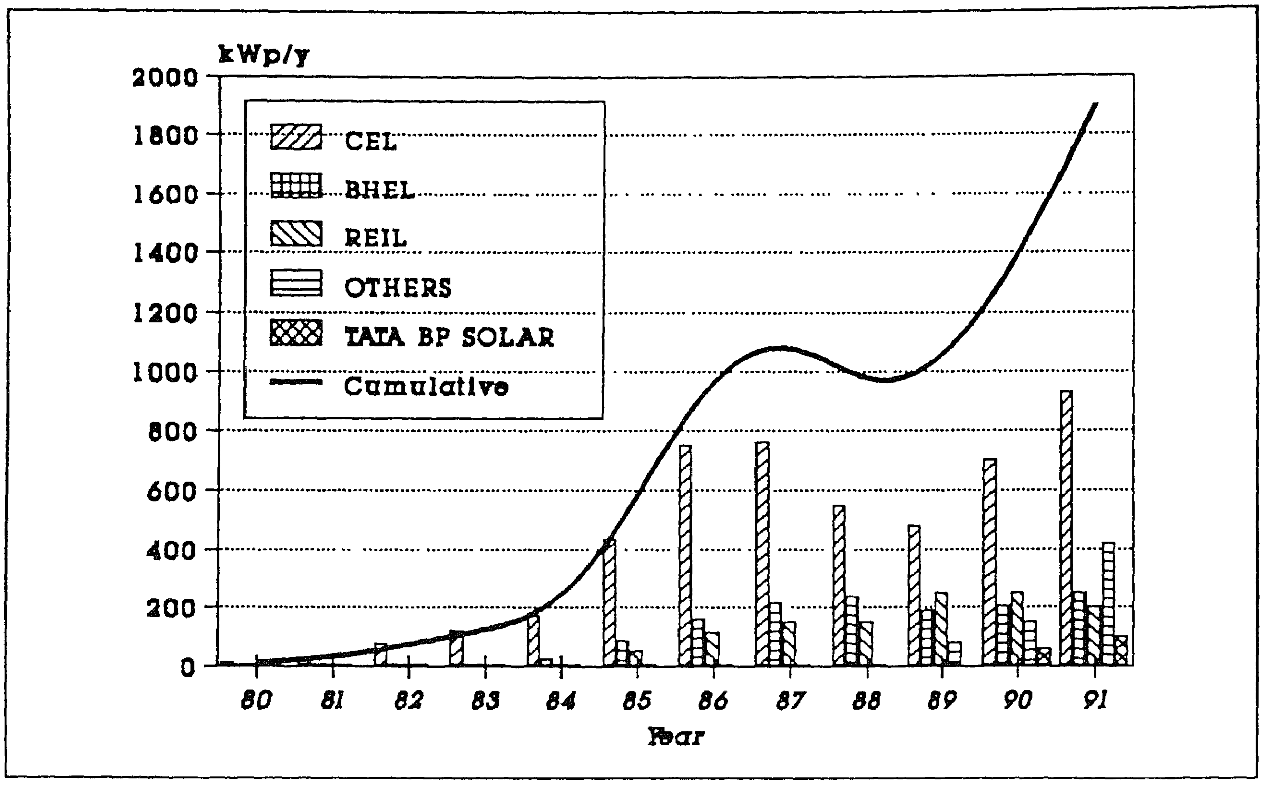
During the period april 1984 to March 1988, BHEL increased their its annual production from 28 kWp to about 220 kWp. Thus, the total annual Indian production of modules was more than 1,200 kWp during the period April 1987 to March 1988. Subsequent year showed a declining trend mainly due to problems in availability of wafers. Last two years have shown a growth rate of more than 35%. The capacity utilisation ratio of the industry is only about 33%. It averages at 39% for central and state public sector undertakings, while the ratio for private sector is only 23%.

Exhibit 2.3 shows the annual PV device production in India during the period 1980 to March 1991.

Table 2.5 : Solar Photovoltaic device manufacturers in India

Name of company	Central Public Undertaking			State Public Unit	Private Sector Units			
	CEL	BHEL	BHEL	REIL	Suryovonics	Tata BP Solar	RES	Udhaya
Location	Sahibabad	Bangalore	Gurgaon	Jaipur	Hyderabad	Bangalore	Hyderabad	Coimbatore
Products	PV cells modules & systems	PV cells modules & systems	a-Si modules	PV modules systems	a-Si cells	PV modules & systems	PV modules & systems	PV cells/modules
Investment (Rs)	NA	NA	180 million	NA	15 million	30 million	8 million	NA
Installed capacity	1.7 MWp	.25 MWp	0.5 MWp	1.0 MWp	1 MWp	0.5 Mwp	0.5 MWp	.3 MWp
Capacity addition		25 MWp			2 MWp	0.5 MWp		
Production 91-92	.93 MWp	23 MWp	Nil	.2 MWp	------------------> .52 MWp ------------------------>			
Technology	Monocrystalline/ polycrystalline	Monocrystalline	Amorphous	Monocrystalline	Amorphous	Monocrystalline	Crystalline	Monocrystalline
Production status	In production since 1983	In production since 1984	Pilot plant under trial production	Production modules and systems since 1986 with CEL cells	Commenced production in small quantity	Supplying PV systems with BHEL cells	Supplying PV systems with BHEL cells	Production since 1989
Collaborators	In-house R&D	In-house R&D	Glass Tech. Solar Inc. USA	CEL	Energy conversion devices USA	BP Solar UK		In-house

Turnover 91-92 (Rs. crores)	32.5	9	Nil	7		2		
Foreign equity	NA	NA	NA	NA	80%	40%	NA	NA
Marketing channel	Direct	Direct		Direct		Dealers		Direct
Additional information		Concentration on systems Railways, communication	Equity with DNES	Small systems	100% export unit	Street lighting concentration in Andamans	Equity with APEDC	-



Ehibit 2.3: Annual PV production in India

3.0 Promotional Polices and Incentives

The Government of India, through the DNES, has been propagating and supporting various PV programmes in the country. It has also extended, from time to time, various fiscal incentives to the industry as well as users for manufacturing and using such systems and devices.

These fiscal incentives are briefly discussed in subsequent sections.

3.1 Income Tax

Government of India has announced 100% rate of depreciation under the Income Tax Act in respect of renewable energy devices vide Ministry of Finance Notification No. S.O.276(E) dated 1.4.1987. Bedsides, depreciation is also available to many items on different rates.

3.2 Custom Duty Exemption

The Government of India has substantially reduced the Custom Duty on the import of machinery/components required for the manufacture of instruments, appliances or equipments which function with the aid of non-conventional forms of energy etc.. Details of these concessions are given in table 3.1

3.3 Central Excise

PV devices and systems such as silicon in all forms, solar cells and panels have been exempted for the payment of central excise.

3.4 Sales Tax/Central Sales Tax

States/union territories have issued notifications exempting general sales tax/central sales tax on sale of PV systems in the respective states/union territories.

3.5 Institutional Finance

Financial institutions have agreed to treat institutional credit for the manufacture and installation of renewable energy items on the same terms and conditions as are applicable to the priority sector.

Those eligible under the DRI scheme can also avail of the facility of institutional finance for using renewable energy appliances for productive purposes.

The NRSE industry is also eligible under the existing deferred payment schemes of financial institutions.

With a view to develop and commercialise NRSE systems and devices on a wider scale, the Government of India has also established a public sector undertaking namely, Indian Renewable Energy Development Agency Limited since March 1987. This Agency had been providing loan on soft term (5 to 13 %) to the industry as well as users for the manufacture or use of NRSE systems and devices.

Other than IREDA, the following financial institutions can be approached:

1. Industrial Credit and Investment Corporation of India (ICICI).
2. Industrial Development Bank of India (IDBI).
3. Industrial Finance Corporation of India (IFCI).
4. Risk Capital and Technology Finance Corporation of India (RCTC).

Foreign Collaboration

In order to attract foreign industry to invest in India market, the government of India has modified its policies. The joint ventures can now be formed in India with 51% equity participation by the foreign collaborator. Such policies are geared to increase the use of PV power in the country.

Table 3.1 Custom duty on various PV Devices

Notifications	Item	Purpose (for the manufacture)	Custom duty leviable	Auxiliary duty
No. 94/92 customs and No. 97/92 customs	Dopants or Doping Sources in all forms and with or without precious metal constituents	Semiconductor devices, silicon single crystals or wafers	35% ad Valorem	5%
No. 97/92 customs	Semiconductor grade monocrystalline silicon in the form of bars, rods or ingots	Undiffused, epicoated or diffused silicon wafers, semi-conductor devices	35% ad Valorem	5%
"	• Aluminium paste • Ethylene vinyl acetate sheets (EVA) • Primer for EVA • Polyvinyl fluoride (TEDLAR) • Tedlar Aluminium • Tedlar • Crane glass • Tedlar coated aluminium sheet • Phosphorous oxychloride • Halo carbon (CF_4)/ Freon gas • Tinned copper mesh interconnect • Toughened glass with low iron content and transmissivity of minimum 90% or above	Solar cells/modules	"	"
"	• Graphite beams • Graphite heaters • Graphite hot zone parts • Aluminium oxide dressing stick • Silicon carbide dressing stick	Semiconductor devices, silicon in all forms	"	"
"	• Graphite jigs/block/rods or plates	Semiconductor devices, monocrystalline silicon ingots/wafers	"	"
"	• Screen mesh of stainless steel polyester/metallised polyester or nylon (in sizes of mesh 60 or above)	Semiconductor devices components	"	"
No. 95/92 customs	• Solar cells and modules		30% ad Valorem	5%
	• PV systems		50% ad Valorem	5%

4.0 Existing Market and Marketing Arrangements

Traditionally electrical energy production, sale and marketing in India are controlled by the Government. According to the National Five Year developmental plan, the supply of electricity to various parts of the country is the duty and responsibility of the Government. The government of India in association with different State Electricity Boards supplies electricity at affordable cost to the consumers including those in remote corners of the country. Except in a few states like Maharashtra and Tamil Nadu, private sector had been permitted to produce electricity only for captive consumption. The implications of such a scenario is in the form of dominance of government sector on the Indian PV market. This being the case, the largest buyer for PV systems is the government sector which essentially uses them for the supply of electricity to far and remote places and demonstration projects. The other market segment for PV is commercial in nature to meet essential load requirements mostly for telecommunication, data logging and transmission, various applications in railways etc.. Shipments in this commercial sector have been very limited. Currently, the manufactured PV systems in India do not cater to the consumer market segment (exhibit 4.1). Sections below briefly discuss some of the major applications using photovoltaic systems in India.

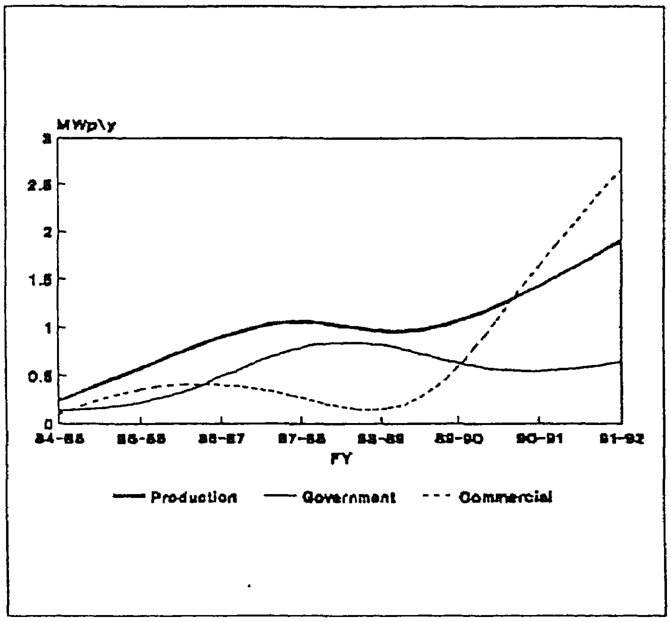


Exhibit 4.1: PV market and total production in India

4.1 Applications and Products

4.1.1. Range of Applications

Water Pumping for Irrigation and Drinking

Solar photovoltaic systems have been used for pumping water especially in areas where human labour or animals are the principal power source. About 1180 PV pumps have been deployed in different parts of the country for meeting drinking and irrigation requirements. These PV systems have been considered appropriate alternatives for drinking water supply to unelectrified locations under the Water Technology Mission implemented by Department of Rural Development. PV water pumping systems do not require any storage batteries and therefore their maintenance requirements are low.

Rural Electrification

In India over 70 percent of the population live in villages. Out of 5,79,132 inhabitated villages as per 1981 census, 4,81,898 have been electrified upto July 31, 1991. The remaining villages are dispersely located, inaccessible and in difficult terrain. These villages are characterised by low load potential, low load factors and low population. Most of them are at considerable distance from the utility grid. Electrification through PV systems in these areas is a better option. So far about 8000 unelectrified villages and hamlets have been electrified through solar photovoltaics. These systems are stand alone systems. The centralised systems for providing domestic lighting, street lighting and meeting other electrical requirements of small unelectrified villages range from 1 kWp to 10 kWp depending on the needs of the community. The systems are specifically designed keeping in mind the necessity for unattended operation and ease of maintenance. So far 50 such systems with a total of 251.33 kWp capacity have been commissioned in different states of the country.

Community TV and Lighting

With the expansion of TV network to cover large areas in the country, there exists a need for installing community TV sets in thousands of villages including unelectrified areas. Even in the electrified areas it may be preferable to use PV power system in view of uncertain nature of the grid supply. In all around 3050 systems for this kind of application have been supplied to many villages including several remote ones. A large number of these systems are for use with Direct Reception Sets (DRS) making possible the advent of television in many inaccessible locations of the country.

Off-shore Platforms and Oil & Gas Pipelines

The country has undertaken an ambitious programme of off-shore oil and gas exploration and production as well as laying of pipelines for the transportation of oil and gas. PV systems provide power for telemetry and communication requirements of off-shore oil/gas production platforms as well as communications, telemetry and cathodic protection along onshore pipelines. PV systems for off-shore applications call for a high degree of sophistication in design and performance due to the extremely unfavourable environment of flammable gases and vapours, and the remoteness of the site. The modules used have to pass severe environmental and safety tests conducted at the Central Mining Research Station, Dhanbad. About 36 such systems have been supplied to ONGC. These are characterised by very special kind of BOS components so that satisfactory performance is obtained in an environment which is both corrosive and flammable.

Telecommunications

Photovoltaic systems are ideal for use in charging batteries which power the communication equipment used by the Department of Telecommunications (DOT) and the Railways. Since the stations are often on hill tops, conventional electricity is unlikely to be available, thus making PV modules a cost-effective energy source. Electrically controlled battery charging and load management systems are also provided along with these systems which include VHF, UHF and microwave transmission equipment, rural telephone exchanges, very low power TV transmitters etc..

Railways

Besides telecommunication requirements, the railway network also needs power for signalling, panel interlocking, lighting at stations and level crossings, etc.. Large stretches of railway network have no assured supply of power today. PV systems in various forms are ideal for these applications.

Defence Requirements

PV systems are being used by the Army, Navy and Air force as well as security organisations such as BSF, ITBP, etc. for their communication requirements as well as power for boarder post camps. Specially designed, close packed foldable modules, have been manufactured for such applications.

Other Applications

These include use of PV modules for battery charging, power for mobile devices such as pesticide spraying, vaccine refrigeration and ice pack freezing etc..

4.2 Typical Products

Photovoltaic device essentially is an electricity generator, hence, any system or appliance driven by electrical power can be operated using PV. The PV generated DC electricity can be converted to AC and/or conditioned appropriately as per the requirements of the load. The range of PV powered products, is unlimited and can stretch as far as the system designer's innovations can go. However, utilizability, field reliability, cost factors and other region specific parameters limit this product range to a few products which are accepted well and used extensively by a particular user community.

In India, the product development has traditionally been aimed at institutional user rather than on individual user. As a result, till recently, the most common PV products developed and utilized in India were various forms of lighting units catering to community lighting requirements. As the programme diversified and caught the interest of commercial organisations, product design also underwent a change. Tailor-made products for specific applications like those for off-shore ONGC platforms, light-weight battery chargers etc. were developed and successfully utilized by many such organisations. In fact, most of the PV products developed during the initial phases of the programme, were modified later according to the specific needs of the users. Water pumping unit is one such example.

A list of products developed for various applications and brief description of a few major products is discussed in subsequent sections.

4.2.1 List of PV Products

Table 4.1 lists majority of PV products developed in India.

Table 4.1: PV products developed in India

Portable lanterns
Stand-alone street lighting
Shallow-well water pumping
Airport obstruction warning systems, unmanned railway level crossing systems, complete railway station lighting, cathodic protection systems for oil and gas pipelines, power systems for telemetry and navigational aids, portable light weight battery chargers, power for rural telephone exchanges, microwave repeater stations.
Direct reception Television system and lighting
Community lighting system
Complete village power packs
Medical refrigerator system and ice packs freezers
Power system for off-shore well-head platforms
Power supply for very low power television (VLPT) transmitters
Other systems, including cathodic protection, railway signalling and railway station power systems, data collection platforms, weather monitoring stations, etc.

4.2.2 Brief Description

Street Lighting Systems

One of the first system to be introduced under the PV demonstration programme was the Street Lighting System (SLS). It has evolved through three successive stages, namely:

i. Single module, three hour operation, fluorescent lamp with timer control; automotive lead-acid battery
ii. Two module, six hour operation, fluorescent lamp with timer control; automotive lead-acid battery and
iii. Two module, all night operation, with compact fluorescent lamp (CFL), day/night sensor and automotive lead-acid battery.

The first two systems have faced innumerable operational problems, especially failure of timer control and battery protection systems and have had unfavourable response from beneficiaries. The third system, which has been introduced during the last two years has been eliciting a far better response and providing greater reliability.

Domestic Lighting Units

The introduction of domestic lights on an extensive scale is again relatively recent. Three types of domestic systems have been taken up:

1. Fixed domestic lighting units (one module, 2 CFLs of 7 W with battery and controls); cost Rs. 9,000/- approximately.
2. Portable lighting units - lanterns (10 W module, 5-7 Watts CFL and sealed battery); cost Rs. 5,000/- approximately; and
3. Service connections from Photovoltaic Power Plants, for monthly payments Rs. 20-50 per connection.

Beneficiary's interest has been found to be strong in the case of domestic lighting units in terms of their willingness to meet a substantial part of the cost on their own. Domestic lighting units or portable lanterns appear to be cost-effective in comparison with kerosene lanterns on the basis of the cost per lumen output of the system. However, this is yet to be widely appreciated and accepted.

Community PV Lighting Systems and PV Power Plants

At the village level, two types of systems have been introduced:

i. A 300 Wp PV installation for the community centre in villages, largely comprising of lights and television;
ii. Village-based PV power units.

So far, 938 community PV systems have been installed. The evaluation of these systems show that wherever the local establishment has taken care of such installations, both in operation and maintenance, they have elicited satisfactory response from the beneficiaries. The beneficiaries have shown willingness to pay for the service rendered, although the payment is unlikely to be able to cover the present high cost of installation.

During the last three to four years, about 50 village-based power plants have been installed, a major portion of it in the state of Uttar Pradesh. These power plants range in the capacity of 2 kW to 10 kW depending on the size of the village and the nature of loads. A typical village-based PV power plant consists of an array; a battery bank housed in a small shed, a power conditioning unit, meters and controls and distribution system. The connected load is mostly for lighting, TV, Radio and drinking water supply pumps. In a few installations, one or two irrigation pumps are also part of the connected load. Almost all these installations are in unelectrified and remote areas where electricity supply from the grid is unlikely to reach in the foreseeable future. PV power plants, have proved to be a better technical solution than individual dispersed installations like street lights.

Solar Water Pumping

Solar pumping demonstration activity has so far relied largely on a 360 Wp array coupled to a DC motor-driven mono-block pump suitable for lifting water from open wells against a total head of about 7-8 metres. Over 1,000 such pumps have been installed in various parts of the country. However, pump capacity has not been found to be suitable either for drinking water supply applications or for micro-irrigation, except perhaps in the state of Tripura, where small land holdings and low pumping needs have contributed to the better user response.

A higher capacity pump comprising 600-800 Wp array and a disk motor pump-set has been developed and tested. The pump is to be utilised for the demonstration programme in place of the earlier small capacity pump. To cater to the requirements in areas where the water level is below 50 feet, deepwell submersible pumps have been utilised. Over 100 such pumps have been established under Technology Mission on Drinking Water Supply in problem villages which have been chronically deficient in potable water.

Other Products

Numerous other products have been developed in the country. Among these, the following are already attracting considerable attention from potential users in India:

i. Solar refrigerators for vaccine preservation: about 18 vaccine refrigerators have been field-tested. Feedback from these tests indicate that operational problems still exist and design improvements are necessary to improve reliability.

ii. Direct receiving dish antennae TV systems: Under demonstration programme, 100 no. of above systems powered by photovoltaics have so far been installed. With 20-25% of the country still not being adequately covered by TV transmission, there is a good potential for this application.

iii. Rural telephone systems: A commercial order has been placed by Department of Telecommunication, Government of India, for supply of 20,000 PV power packs for mini telephone exchanges at village panchayats during 1992. Each pack consists of 2 modules and storage unit (70-90 W) for rural telephone systems. Similar orders are expected for such systems in the coming years.

iv. Battery charging for portable communication: Small PV units (30 W capacity) have been employed by police and defence personnel. This has opened up possibilities for extensive user of PV units in para military, defence and remote area communications where portability and freedom from carrying fuel is an important consideration.

v. Cathodic protection of oil and gas pipelines: These systems are already being employed on a commercial basis. About 10 such systems have already been installed. Considerable scope for increased use of such systems in the country exists.

Table 4.2 gives state-wise break-up of PV systems installation till December 1991.

Table 4.2: State wise break-up of PV installations (till Dec. 91)

		Solar Photovoltaics				
S.No.	State/U.T./ Agency	Street lighting (no. of Villages)	Solar Pumps	Community lighting systems	Domestic lighting/TV Systems	Power Plants (kWp)
01.	Andhra Pradesh	3150	61	6	50	25.00
02.	Arunachal Pradesh	30	14	14	50	2.00
03.	Assam	20	69	-	-	-

04.	Bihar	177	94	103	-	-
05.	Goa	4	2	4	34	-
06.	Gujarat	313	98	50	215	8.00
07.	Haryana	2	8	42	6	20.00
08.	Himachal Pradesh	160	10	9	214	-
09.	Jammu and Kashmir	13	3	3	-	-
10.	Karnataka	95	8	2	-	-
11.	Kerala	89	6	9	-	-
12.	Madhya Pradesh	403	93	64	60	-
13.	Maharashtra	1173	92	49	108	3.36
14.	Manipur	30	2	-	-	4.00
15.	Meghalaya	25	25	-	210	2.50
16.	Mizoram	41	7	1	85	-
17.	Nagaland	38	15	3	8	6.00
18.	Orissa	478	65	34	66	29.00
19.	Punjab	2	5	43	-	-
20.	Rajasthan	705	86	110	-	-
21.	Sikkim	28	2	3	20	-
22.	Tamil Nadu	173	31	18	50	-
23.	Tripura	52	113	112	225	11.70
24.	Uttar Pradesh	305	174	205	1248	58.15
25.	West Bengal	200	39	1	-	-
26.	A & N Islands	149	24	12	330	9.12
27.	Chandigarh	-	-	-	-	-
28	D & N Haveli	-	-	-	-	-
29.	Daman & Diu	-	-	-	-	-
30.	Delhi	4	25	9	71	5.00
31.	Lakshadweep	4	-	2	-	5.00
32.	Pondicherry	-	-	-	-	-
33.	Others	-	-	-	-	-
	Total	7863	1171	918	3050	188.83

4.3 Current Marketing Practices

4.3.1 Government Sector

Marketing, in a true commercial sense, does not generally exist in this sphere. It is due to the fact that most of the systems developed till now are at promotional stage. Their acceptance is established through the governmental support and incentives.

A number of organisations have been created to route the shipments in government sector. The Department of Non-conventional Energy Sources (DNES) in the Ministry of Power and non-conventional energy sources is the overall programme co-ordinator and policy making body for PV in the country. At the state level, State Energy Development Agencies (SEDA) have been established for planning and implementing various PV programmes in the states. In addition, a few Non-governmental Organisations (NGOs) also work in parallel with the respective SEDA for procuring and utilizing PV system within their domain of activity.

Other than the SEDA and NGO, the State Electricity Board (SEBs) as a part of its commitment to provide complete and effective electrification to the entire state also participates in the process of rural electrification using PV systems in areas where economics and other factors and unfavourable for the extension of the utility grid.

The SEDA, as well as SEB plan the utilization of PV systems in the respective state and get it approved by the DNES. While in case of SEDA, DNES supports typically fifty percent of the project finances by way of providing PV modules free of cost, the remaining fifty percent which include purchase and procurement of Balance of Systems (BOS) components, site preparation, installation, commissioning, O&M, consultancy charges etc. are the responsibility of the benefitting state. The SEB projects, on the other hand are financed by the Rural Electrification Corporation (REC), a planning and financing body of the Department of Power. SEB also takes the responsibility of O&M procedures.

In both the cases, the user community is expected to pay a minimal monthly charge towards getting domestic connection. The money thus collected takes care of the salary of the plant caretaker and some small repair and replacement work. Most of the PV systems in the country so far, have been installed using this route.

In addition, sales of a few other system in the government sector have been through the technology missions on drinking water supply and literacy and through the Ministry of Health under World Health Organisation's (WHO) Expanded Programme on Immunization. These systems are PV pumping systems for medium water table (between 20-50 m), lighting units for Adult education centres and night schools and vaccine refrigerators and the ice pack freezers. User community does not contribute towards enjoying these facilities as they are under several welfare schemes of the government.

4.3.2 Commercial Sector

Unlike the government sector, sales here are guided by the normal marketing forces although not so aggressively. The efforts, often both ways from the user as well as the supplier, have resulted in the emergence of a commercial sector for Indian PV systems and have opened up a market for many entrepreneurs to sell their innovative designs and products.

Organisations such as Railways, DOT, ONGC in very specialized application, have found PV systems suitable. Normally, the interested organisation after identifying the potential application, invites tenders from the system suppliers and manufacturers. Alternatively, if the manufacturer or supplier has developed a particular product suitable for such specialised applications, it approaches the buyer to demonstrate the application, thus opening up a new market segment on its acceptance. In a case like this, DNES only plays an advisory role and has no control over either the product specification or their prices. These purchases, specially the modules are not regulated by the DNES and hence prices vary from manufacturer to manufacturer and also depend on the volume of purchase.

This market sector which has opened up recently, has proven the economic viability and commercial feasibility of PV systems for low power and high reliability applications.

4.3.3 Consumer Sector

The consumer sector, commonly identified by milliwatt products e.g. calculator and watches is virtually non-existent for Indian PV manufacturer. The reasons are two-fold. Firstly, most of these small consumer items are powered by amorphous silicon modules which are not yet available in India commercially. Secondly, products which are based on crystalline silicon modules, e.g. solar portable lights, are far too expensive to attract an Indian customer. The result is that although the solar portable light in different designs and configurations, is a consumer product, is sold mostly in government sector with an appropriate and significant financial assistance being provided to the purchaser.

Ideally speaking, the a-Si modules can significantly penetrate the dry cell market because the normal cost barrier is not present in such applications. Although, the unit cost of energy or power is very high in both dry cell and in a-Si products (approximately Rs. 150-200 per kWh for dry cells and in the range of U.S. $ 10-15 per Wp for a-Si module in such small items) the overall product cost is low owing to the fact that these are very low power (in milliwatt) systems. Standard marketing channels for sales of PV systems to institutions in government and in commercial sector are presented in exhibit 4.2

Exhibit 4.2

Sales in government sector

institutions contact SEDA with request to install systems
↓
field assessment by SEDA personnel
↓
Director of SEDA gives approval.
↓
Tenders invited from manufacturers
↓
order placed
↓
system is installed and commissioned
↓

Sales in commercial sector

institution identifies potential application
↓
chooses the suitable product
↓
invites tenders
↓
order is placed
↓
system installed & commissioned
↓
after-sales service by manufacturer for fixed
duration, by user afterwards

Alternatively

manufacturer develops a product
↓
approaches the suitable institution to
demonstrate the product
↓
if accepted, gets the order
↓
install and commission the system
↓
after-sales services by manufacturer for fixed
duration, by user afterwards

4.4 Prices of PV Modules and Systems

The prices of Indian manufactured PV modules vary substantially from one applicational sector to another. While the DNES controls the prices for purchase of modules for government sector, there is no fixed selling price for module to commercial sector sold by manufacturers in private sector. They may be as high as 1.5 times the prices fixed by the DNES. It is mainly due to the fact that private sector industry is sensitive to profit margins for its survival. It is learnt that the selling prices fixed by the DNES leaves marginal scope for the industry to make profit.

Unlike the global market, prices of PV modules manufactured in India have shown an upward trend over the past few years. Although, the prices of wafers in international market have not changed much, the general inflation, convertible value of Indian currency etc. have pushed the module prices to a level of Rs. 225 per Wp for sales in governmental sector. Exhibit 4.3 shows the trend.

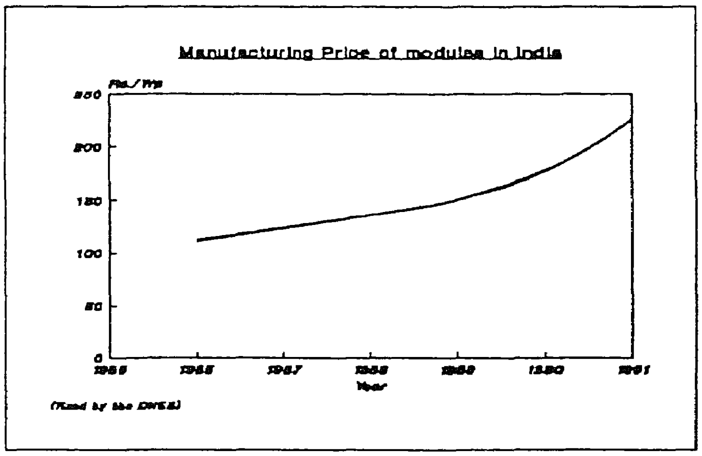


Exhibit 4.3: Market price of modules in India

4.5 Efforts at Marketing and Public Awareness by the Manufacturers

Efforts at marketing by the manufacturer were virtually non-existent till recently, because the major volume of purchase used to be by the government itself. Once the manufacturer or supplier registered itself with the DNES, the share of market was more-or-less assured. The only source of information about the PV products for the purpose of public interest and awareness were technical brochures printed by manufacturers which were available only with the manufacturers. Occasionally, a few advertisements appeared in the 'Solar Energy Society of India' publications. The only contact manufacturer had with the user, was at the time of the system installation and commission and none before or after that period.

The most conscious and sincere efforts at marketing are done by Tata BP Solar India Ltd. by way of establishing a nationwide dealer networkship in addition to liaison offices in metropolitan cities. A recent phenomenon of leading National dailies taking interest in publishing PV related articles in their 'Science and

Technology' or 'Business' section has initiated a public awareness creating activity and introduction of PV manufacturers. Press conferences given by the manufacturers and Televisions programmes at the time of recently held International PV Science and Engineering Conference at New Delhi has certainly drawn attention of the public towards PV systems and their applications.

Such and similar marketing practices on the part of the manufacturer, although at nascent stage, hold the potential of wide scale awareness and interest among likely users who still feel uncertain about choosing a PV system.

5.0 Demand and Supply Forecast

Even after forty years of planning and in spite of huge hydro thermal potential, India is an energy deficit country. Per capita power consumption in India is very low and a significantly high percentage of our villages are yet to be electrified. According to an estimate, there would be a gap of 7000 MW in terms of demand and supply of power at the end of the 8th plan.

If one looks at the energy scene in the country, it appears clearly that conventional technologies alone would never be able to bridge the energy demand-supply gap as indicated in the table 5.1 below:

Table 5.1: Current energy situation

	India	CIS*	USA	China
Per capita electricity consumption (kWh)	250	-	10,000	-
Present installed power generation capacity (MW)	67,000			
Required to reach per capita consumption equal to advanced countries (MW)	2.7 million			
Per capita availability of coal (tonnes)	176	20,066	13,488	1,668
Per capita availability of oil (tonnes)	0.78	30.3	16.0	2.3
Hydro electric potential				

* Commonwealth of Independent States (formerly USSR).

In addition, about 90,000 villages are identified by the government who will not have grid electricity in next several decades. Such a situation indicates that a definite potential for renewables particularly PV, existed in the country. In fact, it has long been recognised that there exists an enormous market potential for PV in India but unfortunately the demand in true commercial sense has not yet been created.

The PV industry in India has not been driven by market development and demand uptil now. Annual PV production has significantly been influenced by the availability of funds from the Government of India and availability of wafers and other materials required by the industry which are not manufactured in India (wafer production on a commercial basis has recently started, however, the supply from this lone manufacturer does not meet the entire demand of the industry). Another factor influencing the module production is the availability of solar cells to module manufacturers who, for their cell requirement, depend completely on the two solar cell manufacturers in the country. If these cell manufacturers are unable to sell solar cells to PV module industry, the entire annual production suffers.

Almost same is the case with the PV market. Since the government sector (directly through sales to SEDAs & SEBs and indirectly through sales in commercial sector viz; Department of Telecommunication, Railways, ONGC etc.) has traditionally dominated the market, availability of funds affects the yearly demand. In addition, most commercial organisations who had started procuring PV systems initially for demonstration, but with intentions of commercial utilization later on, have still not made up their minds to go beyond demonstration. One of the most important reasons being the sub-standard and unreliable performance of commissioned systems mainly due to the fact that users were not aware of what to expect and suppliers were limited, thus limiting the selection of product, ultimately compromising on the quality, reliability and after sales service of the product. Department of Rural Development for use of PV pumping systems in Technology Mission on Drinking Water Supply, ONGC for use of PV systems at its off-shore platforms and cathodic protection of pipelines and REC for electrification schemes to remote villages using PV pole mounted outdoor lights are a few such organisations who have put a virtual halt to the programme for the time being (DRD and REC), or had abandoned it in between and have started again very recently (ONGC).

Further, the industry is still immature, so is the market. It has not even completed one decade of commercial production and utilisation. Any forecast on annual production and/or demand estimated on the basis of norms and methods adopted universally, may indicate a completely unrealistic scenario. For example, in 1989 when DRD placed an order for 200 medium well pumping systems, representing a future market worth of 0.25 MWp per year, the speculations were that a new segment for PV market has been opened. Two years have passed since then, the order has not yet been completely executed and DRD does not have any plans for ordering more such system in near future because they have not been found satisfactory to meet the objectives of Drinking Water Supply Mission. Similarly, the entire industry is gearing up to meet the DOT order of 25-30,000 rural telephones every year; largest in the history of Indian PV industry. This segment of market in its first year itself, is worth 2 MWp. If the DOT decides to abandon the use of PV rural telephones for some reason, the PV industry would once again start limping.

There are other factors as well which affect the demand indirectly if not directly. One such factor has been the absence of post-installation infrastructure and after sales service. Contrary to the common belief that PV is maintenance-free technology, it requires routine O&M practices which include cleaning of panels, checking on loose wire connections, battery upkeep etc. on a daily basis and monthly checks by a team of skilled technicians. This aspect has completely been neglected in India so far resulting in poor field performance and low user acceptance.

However, recently there has been a change of scenario, particularly on the part of the government of India. Several factors appear to be converging to induce a substantial increase in demand for, and use of PV systems in the country in near-term future. These factors are reviewed here:

- Liberalised industrial licensing policy and joint ventures no longer requiring a majority interest Indian participant have already begun to stimulate the global PV industry to enter the Indian market. With it, a wider range of products and applications, improved quality and after sales service, competition in tune with the customer's interest; are likely to be introduced. Notable among them are the Siemens Solar Gmbh, Germany, R&S Systems, Netherlands and Photocomm, Inc., U.S.A.
- Out of total 30065 MW installation of electricity generation capacity during 8th plan period, 2180 MW is to be installed by the private sector alone. Over and above, an additional 3000 MW in private sector is expected to be materialised during this period. The plan envisages an installation upto 1000 MW electricity generation capacity using NRSEs.

Private sector had started installing windfarms for electricity generation in MW range after a few states like Tamil Nadu and Maharashtra had allowed electricity generation in private sector. With this new policy, more industries in the private sector are likely to opt for PV for electricity generation thus increasing the demand for PV cells and modules in the country.

- The New Rural Electrification (RE) policy to be followed for the implementation of 8th plan is conducive to the use of technologies like PV. Out of 50,000 villages targeted for electrification during the period, 10,000 remote ones are to receive electricity using NRSEs.

An assessment of RE during 7th plan has indicated that half of the total T&D losses on all India level (of the order of 22%), are attributable to the RE distributing network alone. Also, in spite of large scale energization of irrigation pumps, there are still over 5.5 million diesel pumps representing a demand potential of 4.7 million tonnes of diesel oil annually, being used. The RE scheme during 8th plan, thus aims at reducing T&D losses and reduce dependence on diesel pumps. The use of PV systems in decentralised mode of operation is suitable to meet these objectives.

- To provide wider opportunities for the rural communities for gainful employment and to improve there income from activities other than irrigation, the Rural Electrification Scheme is planned to be combined with Rural Industries programme. In this context, rural and agro-based industries will be specifically promoted in co-ordination with the rural electrification programme.

5.1 Targets set by the Government of India

5.1.1 Energy: 2001 Plan by DNES

With an aim at facilitating country's successful transition into the 21st century, the DNES sketched the Energy: 2001 plan based on new and renewable sources of energy to meet the total energy requirements of the population which is estimated to be over 1000 million by the year 2001.

The plan is targeted at utilising PV systems for large scale power generation and 50,000 systems for pumping water upto a level of 8 m for lift irrigation and drinking water supply. Summary of the plan Energy : 2001 is presented in table 5.2. The data presented for large scale power generation using solar systems includes both PV and thermal based options.

While the 30 MWe power plant using solar thermal technology was conceptualised and designed during 1985-90, the actual installed capacity was only .7 MWe. In the area of PV, the total installed power generating capacity during 7th plan period i.e. 1985-90 was less than 100 kWp.

As discussed earlier, the execution of the DNES plan depends entirely on the budgetary allocations which were less than Rs. 50 crores for entire PV programme in the country for the period 1984-90.

The future PV market, however, would not entirely dependent on the DNES funding. The commercial sector more-or-less operates independent of DNES for implementing identified PV projects. Also, the new ventures, mostly in private sector with foreign collaboration, do not necessarily have to depend upon DNES for business. They aim at tapping the commercial and consumer market.

Table 5.2: Energy 2001: perspective plan for non-conventional energy source

	1985-90		1990-95		1995-2000		Total	
	Power	Pumping	Power	Pumping	Power	Pumping	Power	Pumping
Energy generation / saving (in MTCR)	0.11	0.008	0.83	0.024	2.84	0.048	3.78	0.08
No. of projects (in MW)	60	1.5	440	4.5	1500	9	200	15
Budget requirements (in crores of rupees)	180	21.25	1320	45	4500	90	6000	156.25
Government share - total budget (in crores of rupees)	72	17	330	18	675	9	1077	44

5.1.2 Market Estimated by the Planning Commission

Based on the experience and popularity of PV systems during sixth and seventh plan periods, the potential requirement of some of the major applications of PV technology during 8th five year plan was estimated as per the following table 5.3.

Table 5.3: Total estimated requirement for PV modules during 8th plan (draft document)

Applications	Requirement (MW)
Pumps for irrigation and drinking water supply	5.0
Rural electrification including power plants	15.00
Off-shore platforms and oil and gas pipelines	0.2
Telecommunications (P&T/Railways)	5.0
Other railway applications	0.5
Community TV and radio sets	0.5
Defence and related requirements	1.0
Consumer applications	0.25
Other applications	10.0
Total	42.45

The total investment support required for the entire programme was approximately Rs. 650 crores out of which Rs. 150 crores was expected to be a contribution from the PV industries.

A revised and re-estimated potential by the DNES indicated a cumulative demand of 30 MW requiring a total financial resources of Rs. 400 crores. The revised target was ten times more than the actual target set for PV during the 8th plan as per the final document. Table 5.4 & 5.5 compare the total MNES demand and financial resources for various PV systems.

Table 5.4: Cumulative installed no. and targets for various PV systems

Applications	Cumulative installed no.	
	During 1984-92	Targeted during 1992-97
Street lighting systems	20,000	2000
Water pumping systems	1200	600
PV power plants (kWp)	260-270	1320
Stand-alone lighting systems (portable and fixed)	6500	23,000
Other applications (kWp)		400

Table 5.5: Summary of budgetary allocations per annum

Five year	Available amount (crores of Rs.)	
	DNES	PV
1984-85	82.6	3.9
1985-86	120.4	6
1986-87	115.45	7.95
1987-88	100.43	8.6
1988-89	105.48	9.5
1989-90	115.75	10.25
1990-91	-	-
1991-92	-	-
1992-93	-	9
1992-97	862.11	90

5.2.3 Market Identified Under GEF Scheme

Typically, the annual budget for PV is divided between three major areas viz; R&D, demonstration and commercialisation and an identified task force e.g. a-Si programme or National PV Test Centre. The demonstration and commercialisation programme takes about 30-40 percent of total PV funding. In addition to the government of India budgetary allocation for every fiscal year, the DNES also gets funding under International Aid Programmes and Schemes.

Major fundings in the are of PV for international funding agencies is given below:

Table: 5.6: International funding in the area of PV

Donor agency	Project scheme	Duration	Financial Indian input	Details external input
UNDP	Development of a-Si solar cells	August '87 to July '92	Rs. 1.22 crores	US $ 2.94 million
USAID/USA	Establishment of National PV Test Centre	Till June '92	Rs 1.38 crores	US $ 0.59 million
WB/GEF	Commercialisation PV in India	1992-97		US $ 55 million

The recently commenced WB/GEF project aims at commercializing PV systems for efficient lighting, water pumping and rural community services. It would involve the establishment of a revolving fund for concessional consumer financing, infrastructure support for marketing, delivery and servicing of products to support an estimated 12 MWp of PV systems.

5.3 Estimated Demand and Supply

5.3.1 Demand

Till recently, the demand has never exceeded the cumulative annual production of PV industry. Mainly, because government being the largest buyer, annual production as well as market were driven by the availability of government funds. At the same time, production was never enough to exceed the demand to be able to tap export market. Also, Indian products, by way of price and quality, could not compete in the international market and friendly neighbours like Nepal with all intentions of utilising Indian PV products, find that better products at lower price are available from other manufacturers.

With an entry of big names in private sector e.g. Tata BP Solar and possibly Siemens, the market would also undergo a change, not only indigenously but also in export sector. This emerging market is analyzed separately as indigenous market and export market. However, one must realize that the growth of Indian market is sensitive to many parameters. These are:

(i) Import duties on wafer and other raw material required for module production. The cost of wafer for large orders (1 million in no.) averages at US $ 2.4 per wafer in the international market. The equivalent Indian cost at current dollar to rupee conversion rate of Rs. 30, after paying CIF charges of Rs. 4-5 per wafer and paying 35% total import duties, is in the range of Rs. 105-110 per wafer. This cost is almost the same as the one offered by Metkem, the sole Indian supplier for wafers. The availability of wafer and other material at reduced price would create a significant impact on the market by achieving overall cost reduction of systems.

(ii) Tax incentives and other benefits are provided only to corporate bodies. If these incentives are made available to non-corporate users and individuals also, the commercial as well as consumer segment of PV market would certainly be benefitted.

(iii) Except IREDA, no other financial institution has taken the initiative to provide soft loans to manufacturers and users of PV system. Availability of such schemes would act as a drive to expand the existing market.

(iv) The Indian industry largely depends on 100 mm dia single crystalline cells and 30-35 Wp module. While production of low power modules (5-10 Wp) for small power application has recently started, the high power modules (70-100 Wp) which offer lower cost of production per peak watt has not yet started. Similarly, production of multicrystalline silicon cells and large area solar cells has not yet begun in India. It may not be a critical parameter at present, but updating the technology at par with the internationally available one will play a significant role in better market penetration.

(v) Another factor which is likely to play an important role in developing a future market is the user awareness. Many potential users e.g. affluent households in north-eastern region willing to purchase domestic lighting units, are not aware of the existence and benefits of such a system. A market penetration drive combined with development of products based on the requirement of user is likely to expand the future market.

(vi) In addition, the field reliability and single point accountability including effective after sales service would help in developing the credibility and hence, the popularity of PV products.

(vii) For consumer market development e.g. for toys, calculators etc., competition with dry cell manufacturers is likely to be faced as the latter industry might loose its market on account of availability of PV power products using rechargeable batteries.

All these factors, would play significant roles in creating and expanding the Indian PV market. To estimate the market, a REALISTIC scenario is considered which estimates the potential within the constraints traditionally faced by the Indian PV community or in other words Business-as-usual scenario.

Scenario I - REALISTIC Scenario

Unlike the exponential growth forecast for global market, the Indian market is expected to grow linearly with an average 13 percent growth rate per year for the next eight years. The total per annum market is estimated to be 7.4 MWp by 1996-97 which will grow upto 9.8 MWp p.a. by the turn of the century.

The government sector which has traditionally dominated the market by way of demonstration projects will account only less than 10% for share of the total demand in 1996-97 with no change in the scenario in 2000 AD.

The respective growth curves for both the government and commercial sector are presented in exhibit 5.1. As seen, the consumer sector will not open up in near future if the current situation prevails. The commercial sector represented currently the telecommunication applications (both in P&T and railways), ONGC etc. is influenced more by the reliability and the quality of service rather than the price per peak watt. This sector will outgrow the government sector in immediate future as majority of sales which have traditionally been routed through government sector i.e. domestic and portable lights, water pumping for irrigation etc. would attain a point of commercialisation and would thus represent commercial market.

5.3.2 Supply or Production

The total installed capacity in India as on today is 5.75 MWp based on crystalline silicon and a-Si technology. Other than the installed capacity, a cumulative 2.75 MWp additional capacity in the near future has been announced by BHEL, Tata

BP and Suryavonics. The capacity utilisation ratio, however, has been very poor. Even if this ratio improves to 70% both for public and private sector units, all capacity additions are completed and Suryavonics directs 25% of its sales to Indian market as allowed under the new industrial policy, the total production will not go beyond 4.5 MWp p.a. by 1986-97 and by 5.75 MWp p.a. by the year 2000. The current scenario of industrial production is unlikely to change in near future as the constraints identified earlier in this section for market would continue to influence the production in a similar manner. Exhibit 5.1 presents the demand and supply curves under REALISTIC scenario.

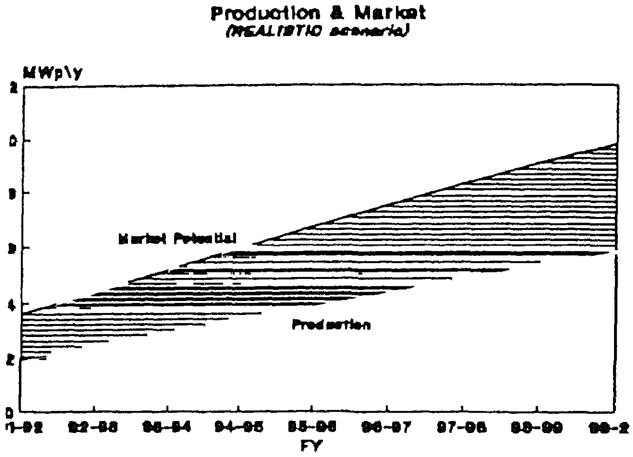


Exhibit 5.1: Production and market forecast

5.4 Export Potential

As per the analysis presented in section 1 of this report, the global PV market would be worth 168 MWp by 1995 and 260 MWp annually by the year 2000 under BAU scenario. Out of this total market 50 MWp share (in 1995) is estimated for PV/diesel hybrid systems only. Although this forecast is highly optimistic, PV/diesel hybrid applications potential has not yet been tapped efficiently by the PV industry. Similarly, the signals and communications market and off-the-grid rural market particularly in countries which do not have an indigeneous industry offer excellent export potential for Indian PV industry.

5.5 Strategies for Market Penetration

The cost of PV has been identified as the most crucial barrier for market penetration. While this may be true in global perspective, there are local factors which are more prevailing in developing an indigeneous market. These factors may be linked to government policies and programmes, region specific social parameters or economic conditions of the likely user The PV market in India has suffered the most because of lack of definite market penetration strategies of the industry.

A few of these specific to Indian market development are discussed here:

(i) The likely buyer, whether a government department (other than the DNES) or a rural costumer, is faced with a new and unknown product category as well as an unknown brand. Very few individuals would have known what exactly is a PV system, and if they decide to buy a system, how much of credibility they should put on an entirely new brand name like X solar products or Y PV devices. If the PV manufacturer is aiming at sales to individuals and/or group, which are not influenced by the government incentive, a credibility and accountability on the product supplier becomes of prime importance.

(ii) Another factor for market development, particularly in India is the reliability and credibility in performance of commissioned PV systems. The acceptability and hence the future of similar or the new products id largely dependent on these factors as most of the systems are supplied to users as substitute to conventional grid electricity.

(iii) Although PV systems require daily minimal maintenance for which a trained caretaker is sufficient, regular checks by a team of highly trained technicians are essential in order to rectify the fault if it occurs. Creating an appropriate service infrastructure which includes nation wide dealers network, a cadre of self-employed technicians and system installers and user awareness by targeted advertising in addition to a minimum 5 years warranty on products should form an integral activity of the market development.

(iv) Innovation in design and system integration as per the site specific and user specific requirements, leading to a competition in the market is the key to success for any product; PV is no exception.

(v) Since the majority of PV industry as well as PV market is supported by the government, the whole PV programme has become very sensitive to government policies. To protect the interest of the industry and the market, a consortium of PV industries should be formed.

(vi) Any new entrant should be able to carve out a niche in an otherwise limited market. Attempts should be aimed at those applicational areas which have not been tapped by Indian or a foreign supplier. Given below is a list of such products and applications:

Product	Applications
Small electric gen-set or portable power supply	Efficient farm houses, remote work stations, commercial set-ups in hilly and forest regions.
Pumping systems in different ranges and designs	Small (upto 10 m) for domestic applications. Medium (upto 50 m) for irrigation. High (up to 150 m) for drinking water supply.
Small refrigerator cabinets	For tourist complexes at remote places e.g. in wild life reserves, in mountain etc.
Bill board for highway advertising	
UPS for mini-computer and data-logger.	For field research stations.

6.0 Options, Approaches and Recommendations

6A Options and Approaches for Setting up a PV Industry

6.1 Technological Options

Technological options for setting up PV industry range from crystalline Si which has traditionally dominated the PV market to tandem structures using GaAs and GaSb which hold the promise for least-cost system in future. Out of all these materials, crystalline silicon is the commercially proven and technologically well-established option as it has directly enjoyed the results of R&D in semiconductor industry. In addition, it is the only technology as of now, which has been found to be feasible for use for power applications. The other material viz; GaAs, CdTe, $CuInSe_2$ etc. have an edge over crystalline Si by way of either high efficiencies or overall less material requirement, and thus holding the potential for low-cost energy generation. They would, however, compete with crystalline Si only if ongoing attempts at making them commercially viable are successful. The following table indicates that crystalline silicon is the most viable technological option for the present and near future.

Table 6.1 : Technological options

GaAs	Theoretically the most efficient PV material. Viable only under high concentration option due to high material cost.
CdTe & CIS	Intrinsically stable and medium efficiency cells. Not yet commercialised. Environmental safety of toxic elements like selenium and cadmium persist.
a-Si	Less expensive, less energy-intensive and less efficient as compared to its crystalline counterpart. Suffers from inherent instability on exposure to sunlight. Suitable for indoor low power applications only, on account of low efficiencies and instability.
Crystalline Si	High efficiency, high reliability and high production cost technology. Majority of the new capacity been installed globally, based on crystalline Si indicating no real challenge to this technology in near future.

6.2 Approach: PV Devices

The next option offer selecting the appropriate technology, is the stage at which the industry should be set up, PV manufacture involves following four components.

1 **Semiconductor material and wafer preparation**

2 **Device fabrication (solar cell)**

3 **Module assembly**

4 **BOS components, system design and integration**

The manufacturing process becomes progressively more complex as one goes up the path from stage 4 to stage 1. Various aspects associated with these components are briefly discussed below:

Semiconductor Material

Although a PV industry can be based on crystalline Si, a-Si and polycrystalline thin film, the practical approach indicates crystalline Si to be the most appropriate technology. This is due to the fact that results of R&D in PV area have traditionally been taking a significant time period to be implemented at commercial production stage. Hence, although intensive R&D efforts globally are aimed at developing suitable PV technology other than based on crystalline Si, the expert analyses indicate the dominance of latter to continue till the turn of the century.

For crystalline Si based industry, the most energy-and cost-intensive stage is the manufacture of EG-Si and its preparation in wafer or sheet form using Siemen's process. The otherwise considered high-technology for single crystal pulling and wafering, using even advanced CZ method, is relatively simple and adaptable.

Device Fabrication

The manufacture of high-quality solar cells on a commercial scale requires proper production equipment meeting stringent requirements of large scale production. These production-lines may or may not be available off-the-shelf. In fact, there are not more than 4-5 suppliers all over the world who can offer cell production lines as per the requirements of the industry. As a result, most manufacturers build there own production lines according to their plant size and other requirements.

Another consideration while setting up a solar cell industry is the availability of wafer, which in India, are manufactured by only one industry. The major portion of the wafer requirement of Indian PV industry is met by imported wafers.

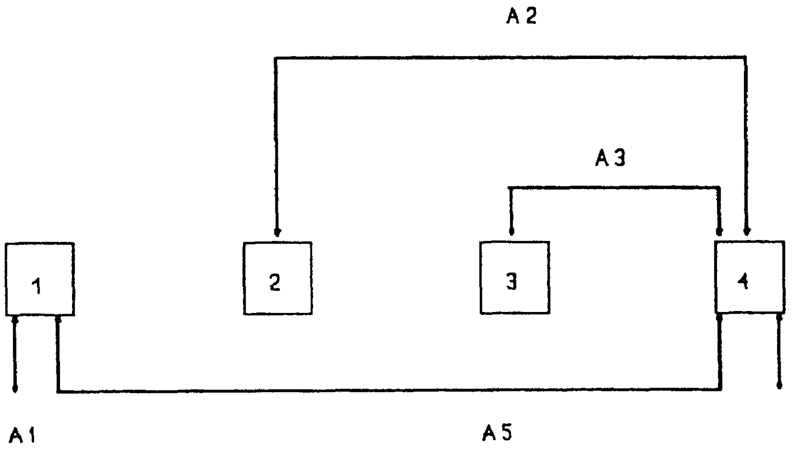
Module Assembly

Module assembly line is a relatively simple and less-cost intensive PV industry. It is a semi-automated process and most of the equipment is readily available. As for raw materials such as etchant, solvents etc. which are locally available, laminating materials which are produced only by a few companies in the world, have to be imported in the country after paying significant customs duties.

BOS Components and System Integration

Design and development of balance-of-system, overall system design and its integration is the smallest and least expensive of PV industry. In the absence of national level standard for such components, there is no check on the quality assurance of these products which are often designed and developed by non-PV experts. The reliability and hence the cost of production is low for this industry.

A PV industry can be set-up following any of the five approaches presented here. While approach A1 to A4 are associated with crystalline Si based industry, approach A5 is typically for thin-film device industry including the a-Si as well as polycrystalline materials e.g. CuInSe$_2$, CdTe and Si.



Approach 1 (A1):

A wafer manufacturing industry for crystalline Si involving feedstock material preparation, purification and crystallization to either sheet or wafer form requires the highest level of investment but also offers greatest security as it eliminates the uncertainties associated with the availability of feedstock material or wafers from a few existing suppliers. Alternately, purified silicon feedstock material can be purchased and single crystal or polycrystalline silicon ingots or sheets from it can be made. Both the options, although are highly capital intensive, offer the possibility of supplying Eg-Si to the semiconductor as well as to the PV industry locally and to other developing countries. The investment, however, are justified only if a large potential for PV exists in the country.

Approach 2 (A2):

A high level of investment, technical expertise and infrastructure is needed to set-up a device fabrication industry using imported or indigenously purchased crystalline wafers. The cells thus fabricated, can be laminated into a module and PV system designed in-house without involving much efforts.

There are two important considerations for this approach. Firstly, the prices of wafers in the international market vary substantially depending on the volume of purchase (approximately U.S. $ 2.3 per wafer for 1 million order, could be as high as U.S. $ 3 per wafer for smaller volumes). Secondly, the possibility of the technology for production becoming obsolete is significantly high. CEL's cell production line which was set-up a decade earlier has already become obsolete.

Approach 3 (A3):

Another approach consists of procuring finished cells either from indigenous sources or by importing and assembling them locally into modules. Modules thus made are integrated with in-house developed BOS to design and develop a range of PV systems suitable for various applications. It is possible to enter into a technical collaboration with a foreign cell manufacture with a buy-back arrangement.

The approach requires moderately high investment and offers opportunity for employment generation as most of the procedure is manual.

Approach 4 (A4):

Balance-of-system components can be developed indigenously and modules can be purchased to integrate PV system and supply to various user organisations. About 15 small units belonging to PV industry following this approach are currently in Indian market.

Approach 5 (A5):

Although feasible for crystalline silicon based industry also, is more applicable to thin-film PV technology. For a-Si as well as for other polycrystalline thin-film, a single pilot plant following the substrate in-module out route can be set up. Systems based on such modules can be designed and developed within the same facility.

Although any of the approaches can be followed up to set up a PV industry, in Indian context, it has to be viewed in a different perspective. The Indian PV industry depends partially on Metkem for the supply of silicon wafers. The rest of the demand (60-65%) is met by importing wafers from various countries. The cost of imported wafer at current convertible value of Indian currency and after paying import duties is roughly 1.5 times the international price at which wafers are purchased. Metkem prices are higher than international price by a factor of 1.5, but in the absence of any other competitor, Indian cell manufacturers depend on Metkem solely. If wafers are available to Indian cell manufacturers at competitive international prices, the cost of production of PV devices can substantially be brought down.

However, decision in favour of setting up a wafer industry has to be weighed in view of the following:

- The investment required to set up a wafer line are substantially high. Economic viability of the project needs to be worked out very carefully for two options viz., (a) wafer line for in-house requirements only, (b) for indigenous as well as export market.
- At present, there are only two solar cell manufacturers viz; BHEL and CEL. There combined annual requirement is expected to be in the range of 1.25-1.5 million wafers. The other module manufacturers, e.g. Tata BP Solar import cells manufactured by BP solar under a buy-back arrangement. Udhaya, REIL and RES have not yet entered into cell processing industry. Hence, the real indigeneous market for wafer is represented by BHEL and CEL only.

- Wafer industry is essentially a semiconductor industry. Silicon wafers for PV devices is only a specialized product. With the recommissioning of semiconductor complex, Chandigarh, a likely competitor, (though not for PV industry), is already existing. It is also worthwhile looking at the reasons for failure of Siltronics in Hosur near Bangalore and Super Semiconductor, in Calcutta who were supplying CZ wafers to Indian PV industry during 1988-89.
- Considering the international market, particularly in other developing countries, it would be profitable to set up an integrated PV industry (wafers, cell and modules) under the buy-back arrangement with technical-cum-financial collaborator in view of the exemption in import duties in such cases.

The table below summarises these approaches.

Table 6.2: Considerations for setting up PV Industry

Approach	Considerations	Investments (approx.)
A1	* Requires very high investments, economic viability only if a large potential exists not only for PV but for semiconductor industry also * Extremely energy-intensive industry, difficult to justify for an energy-deficient country like India	Rs. 13 crores
A2	* Inadequate wafer availability at national level, selling price high for lower purchase volumes in international market * High probability of cell-line equipment technology becoming obsolete	Rs. 10 crores
A3	* Initial investments at moderate level * Foreign collaboration with a buy-back arrangement for manufactured modules and systems possible	Rs. 5 crores

A4	* Lack of credit to system manufacturer due to absence of single point accountability * A small-scale unit, can be started by any individual/small group with a few lakhs of rupees as initial investment	A few lacs
A5	* A high capital-and-energy-intensive industry for crystalline silicon * Feasible only for thin-film technology based industry.	Rs. 28 crores

6.3 Approach: Battery and BOS

A very important aspect to be considered while entering into emerging PV market is the quality of the product. This is specially true for PV device manufacturers who depend on the locally available battery and BOS for designing and integrating the system. While the development of BOS for PV can easily be managed by the existing electronics, mechanical and electrical engineering, industry, that for battery requires special skills and technical inputs. The battery suitable for PV applications can neither be the automotive type, nor it can be industrial type. The PV battery is specifically designed and developed as per the following requirements:

- high cycle life
- high capacity appreciation at slow rate of discharge
- good reliability under cyclic discharge conditions
- low equalizing and boost charging requirement
- high watt hour and ampere hour efficiencies at different SOC levels
- low self discharge
- wide operating temperature range
- long life, robust design and low maintenance requirements
- highly cost effective
- stringent quality control during manufacture

Till recently, most of the PV applications were using flat plate automotive type battery manufactured locally. With the increasing demand, all big battery manufacturers viz; Chloride India, Standard Batteries, Amco Batteries, UB-MEC etc.

modified their tubular type industrial batteries to suit the PV applications and named the range as solar PV batteries.

However, for high reliability PV applications like those for navigational aids, off-shore oil platform, etc., imported low maintenance or maintenance-fee batteries were being used. Tata BP Solar is the first PV industry to develop batteries specific for PV applications which are being used in-house as well as exported. The life of Indian PV battery is typically five years. Since the battery life and performance reflect upon the system reliability and cost, the approach should be to use batteries with international performance standards but designed and developed to perform reliably in Indian ambient conditions. It is advisable to adopt the internationally available technology and manufacture the batteries in India. Table 6.3 gives list of commercially available PV lead-acid batteries in India:

Table 6.3: Commercially available PV lead-acid batteries

Company	Product Range
Chloride India Limited, Exide House, 59 E Chowringhee Road, Calcutta - 700 020.	Exide solar batteries in 2 V, 6 V range low maintenance
The Standard Batteries Limited, Vakola, Santa Cruz, Bombay - 400 055.	Solar batteries in 2 V, 6 V, 12 V range low maintenance
UB-MEC Batteries Limited, MEC Factory Road, Yeswantpur, Bangalore - 560 022	Solar batteries in 2 V, 6 V range low maintenance
Tata BP Solar India Pvt. Ltd., A 101, Block II, KSSIDC Multistorey Blocks, Electronic City, Hebbagodi Hosur Road, Bangalore - 562 158.	Solar batteries in 2 V, 6 V range single cells and 12 V range monobloc low maintenance 6 V, 10 AH maintenance free
Amara Raja Batteries Limited, Renigunta-Cuddapah Road, Karakambadi - 517 520, Tirupati (A.P.)	Power plus batteries in 4 V, 6 V, 12 V range sealed maintenance free
Crompton Greaves Ltd., Vandana, 11 Tolstoy Marg, New Delhi - 110 001	Low Maintenance high discharge batteries in 12 V range
Plumac Power Systems (P) Ltd., 8-2-332, Road No. 3, Banjara Hills, Hyderabad - 500 034	Triumph sealed maintenance free battery in 12 V range
Amco Batteries Ltd., Bangalore - 560 001	Amco yuasa battery maintenance free, rechargeable in range 2 V, 6 V, 12 V

6.4 Competitors

The existing PV industry consists of one polysilicon and wafer manufacturer, two solar cell manufacturers, six module manufacturers and about ten small system suppliers. The following table identifies the existing Indian competitors (please see section 2.0 for details).

Table 6.4: Existing Indian competitors

Company/Industry	Product Range
Metkem Silicon Ltd., No. 8, Cathedral Road, Madras - 600 086.	Polysilicon and wafers
Bharat Heavy Electricals Ltd., Control Equipment Division, Post Box No. 2606, Mysore Road, Bangalore - 560 026	Cells, modules, system
Central Electronics Limited, 4, Industrial Area, Sahibabad - 201 010	Cells, modules/systems
Tata BP Solar India Pvt. Ltd., A-1-1 Block II, KSSIDC Multistorey Blocks, Electronic City, Hebbagodi, Hosur Road, Bangalore - 562 158.	Modules and systems, PV batteries
Rajasthan Electronics and Instruments Ltd., 2, Kanakapura Industrial Area, Jaipur - 302 012	Module, systems
RES Photovoltaic (P) Ltd., 6-4-481/2, Krishna Nagar Colony (Opposite Musheerabad Jail), Secunderabad - 500 380	Module, systems
Solar Power Equipments, Kalpataru, 87, Santhome High Road, Madras - 600 028	Systems
Ritika Systems, B-279, Okhla Industrial Area, Phase I, New Delhi - 110 020	Systems
Geetanjali Solar Enterprise, Purbachal Road, P.O. Khagra - 742 103, Berhampur, Murshidabad, West Bengal	Systems
Indfoss (India) Limited, 706-707, Surya Kiran, 19, Kasturba Gandhi Marg, New Delhi - 110 001	Systems
Hi-Tech. Systems, U.P.	Systems
Flexitron, Bangalore	Systems
Amar Enterprises, 12-A Shivpuri, Bulandshahar - 203 001, U.P.	Systems
Surya Jyoti Devices India Pvt. Ltd., E/3 Lajpat Nagar II, New Delhi - 110 024.	Systems
Shivshakti Electronics Pvt Ltd., F-274 Flatted Factories Complex, Okhla Industrial Area, New Delhi - 110 020	Systems

6.5 Characterization and Qualification Testing of Modules

Every module manufacturer is expected to conduct characterization and qualification testing of modules as per the available international standards. Such standards are available from the Jet Propulsion Laboratory (JPL), USA, American Society for Testing of Materials (ASTM), Commission of European Communities (CEC) and International Electrotechnical Commission (IEC), Geneva. In the country, Bureau of Indian Standards (BIS) is developing Indian standards and testing procedures for PV devices and systems. These standards are based on IEC standards. Three Indian standards are published and two more are ready for publication. At the same time, the MNES is setting up a National PV test facility at Gual Pahari in Haryana which would be equipped to undertake routine testing and certification of PV devices and systems.

Till the facility becomes operational and Indian standards are formulated testing of modules would continue to be done in-house by the manufacturer. The qualification and testing include:

Visual inspection
I-V measurements
Insulation test
NOCT measurement
Environmental and thermal test
Mechanical strength

These tests need special equipment, most of which is not available in India.

In addition, for specific applications e.g. in defence, off-shore platforms, railways etc., the user organisations specify that the modules should be tested in a particular laboratory or facility. The manufacturer, in such cases, is expected to get the modules certified by these specified labs.

The details of testing procedures and required infrastructure could be obtained either from the MNES or from TERI.

6.6 Financial Support for Setting up PV Industry

Indian Renewable Energy Development Agency, a public sector undertaking provides soft term loans (5 to 13%) to the industry dealing with New and Renewable Sources of Energy.

Other than IREDA, the following financial institutions can be approached:

1. Industrial Development Bank of India (IDBI)
2. Industrial Finance Corporation of India (IFCI)
3. Risk Capital and Technology Corporation of India (RCTC)
4. Industrial Credit and Investment Corporation of India (ICICI)
5. Programme for Accelerated Commercialization of Energy Research (PACER)

Programme funded by USAID and managed by the ICICI.

Detailed information on IREDA, RCTC and PACER is provided in a separate enclosure.

6.7 Government Policies and Benefits

The Ministry of Non-conventional Energy Sources (MNES, formerly DNES) has been propagating and supporting various PV programmes in the country. It also extends fiscal incentives to the industry as well as users for manufacturing and using such systems and devices.

Import of PV devices, components and systems are subject to customs duty but no duty is charged on silver powder suspension or on silicon resin rubber used in module manufacture. Other items such as EVA, tedlar, and toughened low iron glass are charged an ad volorem duty of 35%. A user certificate from MNES is required for obtaining these concessional duties, without which, the duty is 150%. Silicon for cell manufacture, solar cells and modules are subject to 30% ad valorem and 5% auxiliary duty. On import of PV systems, the duty is 50% ad valorem and 5% auxiliary.

No sales or excise duties are imposed on PV systems. Import of batteries, lamp fixtures, light bulbs, pumpsets, inverters and controllers are subject to 150% duty. The Government of India also offers 100% rate of depreciation under the Income Tax Act for investing in PV systems.

The contact person(s) in the MNES are:

(1) Dr. E.V.R. Shastri,
Director,
Ministry of Non-conventional Energy Sources,
Block No. 14, C.G.O. Complex,
Lodi Road, New Delhi - 110 003.
Phone: 436-0764

(2) Dr. B. Bhargava,
Principal Scientific Officer,
Ministry of Non-conventional Energy Sources,
Block No. 14, C.G.O. Complex,
Lodi Road, New Delhi - 110 003.
Phone: 436-3067

(3) Dr. P. Saxena,
Principal Scientific Officer
Ministry of Non-conventional Energy Sources,
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Lodi Road, New Delhi - 110 003.
Phone: 436-0885

6 B Recommendations for Andrew Yule and Company Limited

6.8 Technology

As per the discussions in section 6.0, the most appropriate technology for PV device manufacture is the crystalline silicon. **Hence Andrew Yule and Company Limited should set up the manufacturing unit for crystalline silicon based solar PV devices.**

6.9 Industry

In view of the emerging Indian PV market, the risks involved and the level of investments, **the recommended approach for Andrew Yule and Company Limited is A3, i.e. procuring finished cells either from indigenous sources or by importing, laminating them into modules and assembling PV systems.**

However, if there is buy-back arrangement of 75% by the technical-cum-financial collaborator, setting up an integrated wafer-cell-module-system line is preferred as it eliminates risks involved with availability of wafers and cells, and with marketing the product in Indian market. The most obvious advantage of such an arrangement would be the exemption from the substantially high import duties levied on raw material.

6.10 Plant Size and Targeted Production Following Approach A3

As seen from the exhibit 5.1, the gap between the market potential and total production is steadily increasing. The estimated market potential by 1996-97 to about 7.4 MWp per annum while the production would fall short by 3 MWp per annum even after assuming that all capacity additions announced will be completed.

In such a scenario, **a 1 MWp capacity plant by Andrew Yule and Co. Ltd. with 70% capacity utilisation ratio would be an appropriate size.** The capacity would take care of uncertainties in the market as well as any new ventures which might come up in future, without much affecting the annual sales.

The production lead-time for the plant would be one year from empty floor to steady production. The entire process sequence for module manufacture and floor plan are presented in exhibits 6.1 and 6.2.

6.11 Required Input Materials and Infrastructure

For a 1 MW module production line, the requirements are as follows:

Major Equipment

Solar cell tester
Solar cell tabbing machine
Solar cell connecting machine
Bussing station
Inspection station
Glass preparation system
Lay up station
Solar cell vacuum pik
Laminator
Assembly and framing station
High voltage test machine
Sun-simulator

Material Requirement

Silicon solar cells
Toughened glass
EVA
Tedlar
Anodized Aluminium frame
Crane glass
Silver paste

Workers

12 operators
1 process engineer
1 maintenance technician

Availability of Material/Equipment

Most of the raw material required for module manufacture has to be imported as all over the world there are very few supplier for laminating material.

The manufacturing equipment by M/s. Spire Corporation, U.S.A. is available in India though their supplier based in Madras (details in annexure). M/s Spire

Corporation offers integrated turn-key PV manufacturing facility. As an option, a few equipments can be procured from sources other than Spire. These are, sun-simulator and solar cell tester and module laminator.

The yellow pages in annexure give a list of suppliers for various materials and equipment.

6.12 Project Profitability Projections

Project Cost : Rs. 575 lacs (approximately)
(excluding land and building)

			Rs. Lacs
1.	Equipment		400
2.	Preliminary expenses		66
	Material	60	
	labour & utilities	6	
3.	Working capital margin		25%
4.	Interest on term loan		80

Assumptions

1. Preliminary expenses include material expended during trial runs which has been assumed at 15% of the first year,s production. Material cost has been calculated at Rs. 200/Wp. Likewise, the labour and utilities expanded during trial runs has been calculated @ Rs. 20/Wp.
2. Working capital requirements has been assumed at 2 months of sales The working capital margin has been taken at 25% of working capital requirements.
3. Interest on term loan during the initial phase of operation (i e. during setting up of projects) has been calculated @ Rs. 20% on outstanding term loan.

Financing Arrangements

	Rs. Lacs
Equity	175
Debt	400
Total 575	

Debt equity ratio has been taken as 2.25:1

PROJECT PROFITABILITY PROJECTIONS

(all figs. in Rs. lacs)

ear	1	2	3	4	5	6	7	8	9	10
roduction (kWP)	0.00	200.00	300.00	400.00	500.00	700.00	700.00	700.00	700.00	700.00
ales (@ Rs. 300/Wp)	0.00	600.00	900.00	1200.00	1500.00	2100.00	2100.00	2100.00	2100.00	2100.00
aterial cost (@ Rs. 200/Wp)	0.00	400.00	600.00	800.00	1000.00	1400.00	1400.00	1400.00	1400.00	1400.00
abour + utilities (@ Rs.20/Wp,10% increase p.a.)	0.00	44.00	72.60	106.48	146.41	225.47	248.02	272.82	300.10	330.11
ross profit		156.00	227.40	293.52	353.59	474.53	451.98	427.18	399.90	369.89
nterest on term loan (@20%)		80.00	64.00	48.00	32.00	16.00	0.00	0.00	0.00	0.00
nterest on WC (@20%)	0.00	15.00	22.50	30.00	37.50	52.50	52.50	52.50	52.50	52.50
epreciation (@20% WDV)		80.00	64.00	51.20	40.96	32.77	26.21	20.97	16.78	13.42
mortisation		7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
rofit before tax	0.00	-26.00	69.90	157.32	236.13	366.26	366.27	346.71	323.62	296.97
ax	0.00	0.00	22.83	81.81	122.79	190.46	190.46	180.29	168.28	154.42
rofit after tax		-26.00	47.07	75.51	113.34	175.81	175.81	166.42	155.34	142.54
ividends			10	15	20	20	20	20	20	20
rofit for appropriation			37.07	60.51	93.34	155.81	155.81	146.42	135.34	122.54
nvestments	-575									
mor+depre	0	87	71.00	58.20	47.96	39.77	33.21	27.97	23.78	20.42
Intt on term loan)* 1-tax rate)		38.00	31.00	23.00	15.00	8.00				
Intt on WC loan)* 1-tax rate)		7.00	11.00	14.00	18.00	25.00	25.00	25.00	25.00	25.00
alvage value										88.00
et inflow	-575	106.00	160.07	170.71	194.30	248.57	234.02	219.39	204.11	275.97
ash flow	-575	106.00	160.07	170.71	194.30	248.57	234.02	219.39	204.11	275.97
IRR (%)	27									

Debt is assumed to be in the form of a term loan with repayment schedule as moratorium 1 year, repayment over 5 years in equal annual instalments, interest rate 20% p.a.

Profitability Estimates

Assumptions

1. Capacity utilisation is assumed to be 20% in the first year of production, 30% in 2nd year, 40% in 3rd year, 50% in 4th year and 70% thereafter.
2. Selling price of module has been assumed at Rs. 300/Wp.
3. Material cost has been assumed @ Rs. 200/Wp. While it is expected that material costs and hence the selling price of modules would decrease, for purposes of this projections the two have been held stable.
4. Labour and utilities are assumed to cost Rs. 20/Wp with an annual increment of 10%.
5. Interest on term loan has been taken @ 20%. Term loan is assumed to be repaid over 5 years in equal annual instalments, with 1 year moratorium.
6. Interest on working capital is assumed at 20% per annum.
7. Depreciation has been taken at 20% WDV.
8. Amortisation of preliminary expenses has been taken over 9 years in equal instalments.
9. Tax rate has been assumed at 52%.
10. Dividends during the 2nd year of production is assumed 10%, at 15% in the 3rd year and @ 20% thereafter.
11. Salvage value of capital equipment is assumed to be NIL.
    Salvage value of working capital is assumed to be 100%, of which 25% (representing margin) is to be retained.

6.13 Recommended Systems and Design

In order to capture the segment of market which has not yet been tapped by any other supplier, it is recommended to develop and introduce new systems, which have not yet been promoted by the Indian PV industry. While the development of systems should be as per the interests of the users, their introduction and promotion should be through a well developed strategy based on the environmental benefits and a reliable alternative to either grid or diesel electricity supply.

Recommended products and the suitable approach for their individual promotion are discussed in following sections according to the priorities in decreasing order.

- **Power Supply (PV Genset)**

Electric gensets manufactured and marketed by several companies have gained popularity not only in small commercial set-ups, but in urban and semi-urban households as well due to irregular power supply by the state grid. These gensets, although are convenient to use and provide a reliable alternative to grid electricity, completely overlook the health and environmental hazards associated with the use of petrol and kerosene.

Photovoltaic genset, essentially for small commercial and domestic set-ups would be technically reliable as well as environmentally-friendly alternative to either grid or petrol-kerosene based gensets commonly used.

Although, the system could be designed as per the power requirements of a chosen set-up, it would be preferred to develop two models in different ranges. The smaller one would be using single module of 35 Wp, 12 V, 40-90 Ah battery (depending on the autonomy required) and required electronics. This system would take care of approximately 4 nos. of 7 W Compact Fluorescent Lamp or 8 W fluorescent lamp (equivalent to 40 W incandescent bulb in terms of lumen output per lamp).

A larger system using 2 nos of 35 Wp modules, can be developed as a high capacity range genset. A still larger system, although possible to design and develop, would not be a portable and mobile genset. It would be a fixed power pack due to its overall weight and surface area.

The portable genset with single or double modules would be suitable for small commercial set-ups e.g. roadside tea shops, restaurants, hotels, health centres, educational societies and high income rural as well as urban households in unelectrified or poorly served area. A fixed power pack in the range of (100-350 Wp) could be introduced to farm-houses, rest-houses and tourist complexes in remote places.

Systems should be designed with high reliability battery offering longer service life, thus making the capital investment more attractive to the customer. While using the long-life battery would not change the PV module capacity in a product, it would offer a more reliable system.

The emphasis should be on the promotion of health and environmentally-friendly electrical genset.

- **Pumping Systems in Various Ranges**

Although, PV pumping systems are being used for both irrigation and domestic water supply, their availability in terms of size and design is very limited. These systems are either submersible AC motor centrifugal pump units meant for water table below 20 m, or are DC motor monobloc surface pumps meant for lifting water upto a maximum total head of 6 m.

There is no system available which is reliable and versatile in the field and caters to the domestic and irrigation needs of a small set-up or individual farms. Two models are recommended for pumping applications. These are Floating motor-pump sets and surface mounted portable pumping system.

The versatility of floating unit makes it ideal for irrigation pumping from canals and open wells. The pumpset is easily portable and there is negligible chance of the pump running dry. A single stage submersed centrifugal pump and brushless DC motor are most commonly used in such type of systems. The PV array can be mounted or a 'wheel barrow' type of trolley for transportation. The unit could be designed either for low head high discharge performance (1 m, 200 m^3/day) or high head low discharge (3 m, 90 m^3.day) using 300-350 Wp PV array.

The other model suitable for open channels, walls, mobile applications, low volume requirements and low-medium head is surface mounted portable pump system. It has a surface-mounted double acting positive displacement pump, PV array mounted on mobile trolley and other accessories e.g. riser pipe, intake filter, DC electronic control unit etc.. The unit powered by a 150-200 Wp PV array would be capable of giving 3-4 m^3/day for a total pumping head of 5 m. Another unit powered by 50 Wp array would provide 2-3 m^3/day for 5 m head.

In both the models, option could be provided for running alternate loads on generated power when pumping is not required. Such loads could be small agricultural equipments.

An appropriate marketing strategy would be to introduce the product as a versatile PV pumping system catering to the needs of small farm irrigation and domestic water supply.

- **Refrigerator Cabinets**

PV powered refrigerators have been preferred over kerosene refrigerators or diesel generators for Universal Immunization Programme of the World Health Organisation. These refrigerators operate on the same principle as normal compression refrigerators but incorporate low voltage DC compressors and motors rather than mains voltage AC types. A PV refrigerators has higher levels of insulation around the storage compartments to maximize energy efficiency, a battery bank for electricity storage, a battery charge controller and a compressor controller to condition the battery electricity as per the specifications of the compressor.

The box type refrigerator design used for vaccine storage can be modified to cabinet type suitable for domestic applications, particularly in tourist complexes established in remote places. PV refrigerators, although, based on the principle of freon gas cycle, are ideal for remote locations, when compared to kerosene powered ones as they eliminate the supply, quality and pollution related fuel problems. A medium size refrigerator could be designed using 150-250 Wp array.

- **Billboard for Highway Advertising**

In a simple and energy efficient form of sign lighting, PV modules installed on the billboard structure, generate electricity during the daylight hours and store it in industrial grade deep cycle batteries. In the evening, the stored electricity powers the luminaire on the billboard. This application of PV is ideally suited for highway signs and billboards where extending grid line is uneconomical. Typically, a 200 Wp array would be sufficient to run two 36 W fluorescent luminaire from dusk-to-dawn to illuminate a 12′ x 24′ size billboard.

- **Automatic Street Lighting System**

Although outdoor street lighting system is well known and well-established PV product for Indian market, there is a scope for continuous design improvement and offering system in various designs and sizes such as decorative garden light, yard and security light, system with two lamps etc..

Usually the system is either installed in stand-alone mode i.e. module, lamp, battery, electronics, pole etc. as an integrated unit or in centralised mode where PV array, battery and system controls are at one place and the lamps are scattered within a specific area. The stand-alone mode is preferred if total number of lamps to be installed are small in number and have to be distantly placed. Centralised system is preferred for a small community.

Each mode offers distinct advantages and disadvantages. The risk of theft and vandalism particularly for battery is very high in stand-alone system. Routine maintenance in terms of cleaning PV panels, greasing and topping up of batteries with distilled water is relatively easy in centralised system. The tilt angle of the PV array can be easily changed seasonally to enhance the collection of solar energy in the centralised system

The performance of stand-alone system is independent of each other. The risk of the complete system shut-down due to fault either at the centralised battery or at the system control is eliminated.

Learning from the Indian experiences, it is recommended that if the community requires in excess of 25 systems, centralised system with battery bank kept at one place should be preferred.

In case of stand-alone system installation, each unit should be designed with either low-maintenance (topping up once in an year) or maintenance free batteries which should be housed at an height equal to the lamp just below the PV panel.

6.14 Proposed Marketing Strategy

Considering the fact that PV market is an emerging market, the sales of products to a mass market are expected to be at a low level initially, but would develop rapidly afterwards. It will take time for the marketing campaign to pick up the desired pace and for consumer awareness to develop. A number of key conditions to be met are:

- Focus on product development driven by consumer felt needs and ability to pay
- Effective distribution of quality product and service and an ability to satisfy customer needs in the long run
- Affordable financing schemes

Price

Since system costs are high, the focus of initial marketing efforts should be on sales to professional and commercial establishments at an introductory price which is not much different for the actual system cost. As the PV products are up-market products (an analogy to washing machine or photocopier market), the important consideration should be the quality and services offered by the product and not the price of competent product.

However, in order to facilitate sales to individuals, Andrew Yule and Company Limited should develop suitable higher purchase and leasing schemes with one of the established financing organizations (may be the subsidiary of Andrew Yule and Company itself). One such scheme could be Employee Finance or Institutional Finance scheme targeted at corporate sector.

Product

PV products, representing an entirely new technology and application, needs to be pushed with a brand name and a clearly identifiable product category (e.g. genset) to create an instant meaning in the customer's mind. A brand recognition, preferably using company's name is likely to improve the sales as it lends added credibility to the product.

Distribution and Service

The most effective way to promote nationwide sales is to have an effective dealer and distributer network. Andrew Yule and Company Limited may utilize its existing distribution network for products and market similar to the PV product. For example, existing dealer network for agro-industry products in its entire geographical spread could be an effective means for distribution of PV products.

The distribution network for PV systems should be responsible for the following:

- Promotion and sale of product in its respective region
- Keeping inventory of spares and products, alternatively ensuring direct supply of products from the factory or regional sales office
- Deliver, install and ensure proper performance of the system. It is required, therefore, that the dealer should either keep technically trained staff on hand for repair service or train local technicians with the help of product supplier.
- Create a niche market and user awareness.

In view of these considerations, it is recommended to choose an existing and established distribution network, preferably associated with one of group's company.

Promotion

Promotion of product should be based on the use of corporate image and an aggressive advertising. Whatever media is chosen for campaigning, the message should be in the form of a small and simple declarative sentence e.g. portable solar genset. Another technique which could be adopted is to use comparisons with existing products. A very effective example in the case of genset could be to compare it with conventional portable gensets on account of environmental benefits.

The promotional campaign for all PV products should adequately highlight the income tax benefits to users. Table 6.5 gives specific recommendations with respect to identified products.

Table 6.5: Marketing Strategies for Identified Products

Product	Price	Product	Distribution	Promotion
Genset	Introductory price not much different from actual system cost	To be introduced with a brand name in a specific product category	Up-market domestic sector through existing dealers of similar products, commercial and professional set-ups through dealers of agro-industry based products	Environmentally-friendly product, tax benefits, promotion through Employee Finance scheme
Water-pumps	- do -	- do -	Commercial and professional set-ups through dealers of agro-industry based products	Versatile product, tax benefits, promotion through availability of loans
Refrigerator cabinet	- do -	- do -	Direct marketing through contacts targeted at tourism industry	Economic option for remote low occupancy tourist complexes, tax benefits
Billboard lighting	- do -	- do -	Direct marketing through agents, approach through billboard designers, advertising agencies	Added advantage in night time advertising specially on highways, tax benefits

6.15 Project Implementation

In addition to the infrastructural and manpower requirements for planning and implementing a new project, setting up a PV industry requires professional inputs from experienced and knowledgeable person(s) at every stage.

The role of project implementor should be:

- To assess the international and national trends in technology and its implementation and be able to adopt/make amendments if required
- To evaluate and monitor involvement/contribution/participation of various groups/individuals.
- To establish the venture as a leader in the field of PV technology.

The desired skills are:

- Proven general management ability, business acumen and leadership qualities
- Experience of more than five years of working in the area of PV, out of which 2-3 years should be in a PV industry
- Knowledge of state-of-the-art of PV technology, system design and integration O&M procedures
- Familiarity with Indian PV programme i.e. Governments of India's policies, working of PV industry, marketing arrangements, user requirements
- Credibility as a PV professional among concerned government departments.

PV YELLOW PAGES

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Bernstein, Mary
-
concentrator cells silicon
point contact cell R&D

ALPHA SOLARCO
11534 Gondola Dr
-
Cincinnati OH 45241
USA 513-771-1690
Schmidt, Edward C.
-
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Fresnel lens concentrators
modules

AMETEK
352 Godshall Dr
-
Harleysville PA 19438
USA 213-256-6505
Meyers, Dr. Peter
-
-
CdTe cells modules

ARCO SOLAR
4650 Adohr La
PO Box 6032
Camarillo CA 93010
USA 805-482-6800
Caldwell, James, Jr.
Dyer, Tom
Gay, Charles
single crystal amorphous silicon
modules terrestrial
residential central station

ASTROSYSTEMS INC
Astropower Division
30 Lovett Ave
Newark, DE 19711
USA 302-366-0400
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Bragagnolo, Julio
Barnett, Dr. Allen
polycyrstal on steel silicon on ceramic
modules

CHRONAR CORPORATION
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PO Box 177
Princeton, NJ 08540
USA 609-799-8800
Kiss, Zoltan
Clemens, Jon
Beecher, Bill
amorphous silicon modules
central station Walklite, Patiolite
battery charger clocks

ENERGY CONVERSION DEVICES, INC.
1675 W. Maple Rd
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USA 313-280-1900
Ovshinsky, Stanford R.
Goldstein, Alexander
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a-Si modules tandem junction
utility commercial
consumer military

ENTECH, INC.
1015 Royal Lane
PO Box 612246
DFW Airport, TX 75261
USA 214-456-0900
Hesse, Dr. Walter
Walter, Dr. Robert
O'Neill, Mark
concentrators Fresnel lenses

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2995 Woodside Rd
Woodside CA 94062
USA 415-851-4105
Lorenzini, Mr.
-
Swanson, Dr. R.
concentrator cells systems

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Lakewood, CO 80228
USA 303-989-8710
Sanders, John
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modules concentrators
central station water pumping
remote power mobile PV

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Kapoor, Dr. Vejay
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CdIn diselenide CIS

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USA 619-576-2647
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Panton, Al
modules polycrystal
lighting remote homes
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San Diego, CA 02117
USA 619-576-7173
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Goff, Bob
concentrators Fresnel lenses

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CdTe modules

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SILONEX INC
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USA 518-561-3160
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single crystal

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Toledo OH 43615
USA 419-537-0131
Brown, James
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amorphous silicon modules
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USA 408-434-6600
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concentrator lens design

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1100 W. Maple Rd
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-
a-Si on stainless polymer encapsulate
utility commercial
consumer military

SUNPOWER CORPORATION
405 NATIONAL AVE
-
MOUNTAIN VIEW
USA
SWANSON, RICHARD M.
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-
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USA
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module research

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USA 713-681-6101
Kotilla, Karl
-
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single crystal modules

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-
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-
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dendritic web modules

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cells modules

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single crystal module
automated plant

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RENEWABLE ENERGY
SYSTEMS BV
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5653 LC Eindhoven - -
THE NETHERLANDS 31-40-520155
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van Rooyen, Mr. J.
van Zoligen, Dr. Ir. R.
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marine consumer products
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PO 477
5140 AL Waalwijk
THE NETHERLANDS 04160 36717
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Gouda, Mark
single crystal

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SCHMIDT, DR. E.
MAASS, KARL
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single crystal modules
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corrosion protection pumps

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8000 Muchen 80 - -
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Roelen, Dr. E.
Merges, V.
Elsaber, B.
amorphous systems parking ventilatior
battery charger

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ARCO SOLAR TV

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Frommer, Dr. A.
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single crystal modules

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Av Belgrano 485
Piso 7
Buenos Aires 1092 - -
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Salgado, Jose Emilio
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BROWN, KEN
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Srinivasan, C.S.
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single crystal modules

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Singal, Dr. C.M.
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single crystal modules

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single crystal

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Sirsi Road
Jaipur 302012 - -
INDIA 61981
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Bhardwaj, M.M.
single crystal

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15, 'Amrut',
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400 086 INDIA 511 4768
Murthy, Dr. M.R.L.N.
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silicon
cells
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PO Box 7432
Bombay - -
400 059 INDIA -
Vora, Pramod
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modules
concentrators

SURYOVONICS
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7-1-27/A Bequmpet
Hyderbad 500016 - -
INDIA (0842) 33827
Varadarajan, M.
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100 Old Pittwater Rd
-
Brookvale NSW - -
2100 AUSTRALIA -
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modules
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EQUIPMENT MANUFACTURERS

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Glendale CA 91202
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equipment mfg inverter

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Omaha, NE 68137
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laminators

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screen printing

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Manning, T.E.
-
hand pumps

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Madan, Dr. Aran
Moore, Diane E.
-
multiple chamber production lines
amorphous silicon

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Canoga Park CA 91304
USA 818-709-7022
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pullers cell manufacturer
module production testers

M. SETEK U.S.A. CO
4962 El Camino Real
119
Los Altos CA 94022
USA 415-961-7134
Kao, Dr. Cheng C.
-
-
single crystal wafer cells
modules assembly line

OXFORD APPLIED RES.
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-
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-
laminators

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HAUSER, DR. C.
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WIRE SAWS

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Hauser, Dr. C.
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wire saw wafer/cell cutting

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THIN FILM COATERS PLASMA POLYMERIZER
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equipment mfg testers
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control equipment systems design